COGNITIVE LOAD AND PUPILLARY RESPONSE

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THESIS

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June 1972

Approved for public release; distribution unlimited.

Cognitive Load and Pupillary Response

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
June 1972

ABSTRACT

25 Naval Postgraduate students were used to test the hypothesis that long-term cognitive loading (information overloading) would result in pupillary constriction. Continuous mental mathematics was used as the cognitive loading task, with control tasks for arousal (looking at photos of nude women) and perceptual motor effort (counting dots with a button-press). Each task had 3 levels of difficulty. Analysis of the percentage change in minimum pupil diameter over 10 continuous trials showed significant effects for tasks and levels of difficulty and a complex pattern of pupillary dilations and constrictions over the last four trials that tended to support the hypothesis. Trends for maximum and minimum pupil diameters, percent change and latency of peak pupil diameters, and blink rates are shown.

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I. <u>INTRODUCTION</u>

A. GENERAL

It is recognized that the increasing complexity of our society has imposed upon the individual greater mental and psychological pressures than have ever before been realized. How the individual adjusts to these pressures is a subject of inquiry that has reached into the many fields of science, resulting in a variety of studies that are producing some knowledge of man's adaptation to his ever-changing world.

One enlightening aspect of present studies is concern with mental loading--the requirement for man to process increasing amounts of information with regard to performing a given task. Measures of accurately evaluating the on-going loading process in a person's mind have been developed and a fuller awareness of man's mental limits is being realized. However, a complete knowledge of what occurs within man as his mental limit is reached, or as he becomes "overloaded," remains to be acquired.

There is here an effort to understand what occurs at this "upper limit" or "information threshold." This experiment was designed to detect mental loading through pupillary changes, to investigate this very factor of increased mental activity or overloading.

B. PUPILLARY RESEARCH

The pupil, traced to the Latin word <u>pupilla</u>, means "little doll" (since a person can see himself in miniature in the cornea of another person). The pupil has long been an object of curiosity to man as he

has pondered his physical nature (Venables and Martin, 1967). Man has introduced into his literature and everyday language such adjectives as beady, tiny, saucer-like, crafty, fiery, and others that have been applied to the eyes, with the notion that they furnish clues to the inner-most workings of the person. While such usage has been carried out rather unscientifically, there is now increasing awareness of the fact that a person's pupils actually do furnish an objective index of his sensory, emotional and mental activity (Hess, 1968).

The three primary factors that influence the size of a pupil at a given moment are: 1) the amount of light that enters the eye--the pupillary light reflex (Hollenhorst, 1968; Breazile and Howard, 1970); 2) the focusing of the eye on near objects--the pupillary near reflex (Rucker, 1969; Schafer and Weale, 1970); and 3) emotional responses to visual stimuli (Hess and Polt, 1960). Knowledge of the pupillary light reflex was first acquired in the tenth century and awareness of the pupillary near reflex was evident as early as the second century. The importance of changes in pupillary size to clinical medicine as diagnostic indicators remained unrecognized until a century ago when Argyll Robertson described a specific pupillary phenomenon as indicative of lues (general paresis)(Lowenfield, 1969). While it was known that the light reflex of the pupil is controlled by the parasympathetic division of the autonomic nervous system, a thorough understanding of the complex role of the sympathetic division which governs pupil size was still lacking at the end of the nineteenth century (Hess, 1968). Hence, during the years following Robertson's discovery, further investigation of the sympathetic division revealed that other nonvisual processes were capable of influencing pupillary behavior. One of the earliest

papers that indicated an association between pupil size and activities of the nervous system was by Bumke (1911). In fact, Bumke emphasized that "in general every active intellectual process, every physical effort, every nervous impulse (whether or not followed by a muscle action), every exertion of attention, every active mental image, regardless of content, particularly every affect just as truly produces pupil enlargement as does every sensory stimulus..."(pp. 60-61).

Interest in pupillary changes waned during the period following Bumke's initial work and investigations during this time were limited to pupillary abnormalities and certain psychiatric studies. In 1960, an article by Eckhard H. Hess and James Polt concerning pupil size and its relation to the interest value of visual stimuli reawakened scientific interest in this area. Numerous studies of pupillary reactions to various stimuli and experimental conditions have resulted.

Coincident with the growth of interest in pupillometrics has been the development of improved means of recording pupillary changes. Reymond in 1888 photographed the pupil to show its size under various states of light adaptation and Reeves in 1920 extended the earlier techniques for taking single pictures of the pupil under various states of dilation. Infrared photography that was developed in the early 1930's made it possible to obtain good pictures of the pupil under very little visible light. Finally, in 1958, Lowenstein and Loewenfeld in conjunction with General Precision Laboratories developed an electronic device which provided an on-line measurement of the changes in pupil diameter (Venables and Martin, 1967).

Current applications of pupillometry can be found in studies of consumer behavior and market research (Krugman, 1964), detection of

latent homosexual tendencies (Davidson, 1966), an alternate type of lie detector (Berrien and Huntington, 1943), ascertaining the ability of airline pilots to remain alert (Yoss and others, 1970), selection of one's friends or partners (Stass and Willis, 1967 and Knoff and Hawkes, 1968), and as an index of preference (Barlow, 1969 and 1970; and Hess, 1965).

II. STATEMENT OF PROBLEM

Studies of pupillary changes during mental activity were first made during the end of the nineteenth century when Heinrich (1896) and Roubinovitch (1900) investigated the effect of mentally solving arithmetic problems in dilating the pupil (Hess, 1968). Since that time, little had been accomplished in further investigating this phenomenon until Hess and Polt (1964) reported the correlation between the difficulty of arithmetic problems and the pupillary dilations they evoked. Hess (1965) further described the changes in his subjects' pupils as a reflection of their individual involvements in their tasks. Further investigations have revealed that the pupil dilates while the subject is engaged in various mental tasks such as mental multiplication (Hess and Polt, 1964; Hess, 1965; Polt, 1970; and Bradshaw, 1968), short and long-term memory tasks (Kahneman and Beatty, 1966; Kahneman, Beatty and Pollack, 1967; Clark and Johnson, 1970; Kahneman, Onuska and Wolman, 1968), digit transformation (Kahneman, Peavler and Onuska, 1968; and Kahneman, Beatty and Pollack, 1967), and forming mental images (Coleman and Paivio, 1969). These and other studies (Simpson, 1969; Simpson and Hale, 1969; Colman and Paivio, 1970; Bradshaw, 1968; and Payne, Perry and Harasymiw, 1968) provide support for interpreting pupillary dilation as an index of mental "effort," "load," or "arousal" during cognitive tasks.

Despite the evidence supporting the influence of mental activity or cognitive load on pupillary dilation, complete acceptance of this fact has not been realized. This is due to the possible existence of

other confounding effects. Bradshaw (1968) specified a need for improved criteria of cognitive load and defined this load to be a function of the rate of presentation of the loading stimuli and of the general complexity of processing requirements. Attempts at conforming to this definition have already been listed, yet the requirement of the subject to respond in some manner in order to indicate his fulfillment of the task was believed adversely to influence the experimental results. These studies had shown that an overt response by the subject was associated with pupil dilation and, as such, was confounding the effects on pupil size produced by his cognitive activity. Simpson's (1969) investigation of this possibility ruled out the influence of confounding effects resulting from the overt activities of the subject and substantiated the use of pupillary changes as an index of cognitive loading. Similar studies (Kahneman, Peavler and Onuska, 1968) on other potential confounding variables with respect to cognitive tasks, such as the subject overtly verbalizing his response and manipulation of incentives, wer conducted. These showed that the effects of such variables were minor in relation to the pronounced effect of task difficulty.

In light of the importance of presentation rate and task difficulty as the major contributors to cognitive load, it is interesting to evaluate a representative cross-section of the most recently performed pupillary studies which have incorporated some form of cognitive loading. Table I lists 21 such studies with their most salient features of stimulus type and duration. It is apparent in nearly every case that the duration of stimulus exposure and task performance was quite brief with an average of 10 seconds per exposure or task. In these studies, a task was presented, the subject then worked on the task, and finally, his answer was elicited. It was noticed that the pupil dilated furing the presentation and

performance sections of the trial and a gradual contraction resulted immediately following the subject's verbal or motor response. The verbal or motor response "released" the subject from any continued cognitive loading and the contracting pupil indicated the loss of the subject's interest in the problem presented him. Bradshaw (1968) reported the continued dilation of the pupil if the subject is instructed not to give a final response or if he is required to prolong his mental task. Despite his trial lengths being but 6 seconds, he noted a gradual decline in dilation occurring during exposure to a block of uniform material, and he attributed this to the decline in arousal.

The purpose of this study, then, is to investigate further Bradshaw's procedure of extending the time over which a subject is not allowed to give an overt response and to evaluate the effects of this procedure in producing an "overloading" of the subject's mind, as evidenced by his pupillary reaction. The studies shown in Table I were of such short duration that any possible evidence of cummulative cognitive overloading was not noticeable.

It is hypothesized that by subjecting an individual to long-term stimulus presentation requiring continuous mental effort, an overloaded state can be attained which will result in a gradual contraction of the individual's pupil, from its dilated level. Pupillary contraction during this overloading period is expected as evidence of a possible physiological release afforded the mind as it is unable to cope with the cognitive load placed on it. This hypothesis is tested against simple decline in arousal and fatigue from the prolonged physical effort required.

TABLE I

PAST PUPILLARY STUDIES INVOLVING COGNITIVE LOADING

Nature of Study	Conducted By	Stimulus Type	Task/Exposure Time (sec)	Adaptation Time (min)	Inter-Stimulus Time (sec)
Load on Memory	Kahneman & Beatty (1966)	Verbal-Nouns Digits	5-15	Unknown	Unknown
Threat of Shock	J. M. Polt (1970)	Verbal-Multi-plication Problems	Up to 20 sec. per problem	2	Unknown
Sociometric Choice & Pupil Response	Koff & Hawkes (1968)	Visual-Photographs	10	Unknown	Unknown
Pupil Size as Index of Preference	Barlow (1969)	Visual-Photos	10	Unknown	Unknown
Pupil Changes & Stimulus Uncertainty	Bradshaw (1968)	Auditory-Warning Signal	15	Unknown	11-19
Attitude & Pupil Size	Hess (1965)	Verbal-Math Problems	10	30 sec.-10 min.	Unknown
Pupil Changes to Visually Presented Words	Polt & Hess (1968)	Visual-Slides of words	10	Unknown	1
Pupil Size and Recognition Threshold	Hutt & Anderson (1967)	Visual-Slides of words	10	Unknown	Unknown
Pupil Dilation & Information Processing	Carver (1971)	Visual-Reading Cards	0.63 1.08 min.	Short Time	1 min. or more

(Continued) TABLE I

PAST PUPILLARY STUDIES INVOLVING COGNITIVE LOADING

Nature of Study	Conducted By	Stimulus Type	Task/Exposure Time (sec)	Adaptation Time (min)	Inter-Stimulus Time (sec)
Perceptual Deficit During Mental Task	Kahneman, Beatty, & Pollack (1967)	Auditory-Digits Visual-Binaview Display	10	Unknown	Unknown
Pupil Changes in Mental Tasks	Beatty & Kahneman (1966)	Auditory-Telephone Numbers	12	Unspecified	Unknown
Arithmetic Problem Difficulty on Pupil Dilation	Boersma, Wilton, Barham, & Muir (1970)	Visual-Cards	20	Brief Period	60
Pupil Size and Problem Solving	Bradshaw (1968)	Auditory-Arithmetic and Word-Game Problems	15	15	Unknown
Pupil Size in Relation to Mental Activity	Hess & Polt (1964)	Verbal-Multiplication Problems	3-30	Several Minutes	5-10
Pupil Response & Mental Activity	Schaefer, Ferguson, Klein, & Rawson (1968)	Auditory-Digits and Multiplication	1-10	1	10
Pupil Response & Sexual Interest	Scott, Wells, Wood & Morgan (1968)	Visual-Nude Pictures	10	10	1

(Continued) TABLE I

PAST PUPILLARY STUDIES INVOLVING COGNITIVE LOADING

Nature of Study	Conducted By	Stimulus Type	Task/Exposure Time (sec)	Adaptation Time (min)	Inter-Stimulus Time (sec)
Pupil & Galvanic Skin Responses & Imagery Task	Coleman & Paivio (1969)	Auditory-Nouns	10	5	10
Pupil Response & Sexual Stimuli	Good & Levin (1970)	Visual-Nude Slides	10	1.5	Unknown
Pupil Response & Memory Task	Clark & Johnson (1970)	Auditory-Nouns	2	Unknown	2
Task Responses & Pupil Size	Simpson (1969)	Auditory-Pairs of Tones	0.5	Unknown	0.5-10
Pupil Response as Activation Measure	Nunnally, Knott, Duchnowski, & Parker (1967)	Visual-Slides	10	3	Unknown

III. METHOD

A. DESIGN

The experiment was a randomized block design with 3 x 3 factorial treatments. The independent variables were three major tasks to be performed by each subject (mental mathematical operations, dot-counting, and viewing pictures of girls) and three levels of tasks difficulty (easy, moderate, and difficult). The dependent variables were: 1) baseline, peak and minimum pupil diameters, 2) peak pupil diameter and button-press latency times, and 3) eye blinks per task.

The three tasks employed in this experiment were specifically chosen for their proven capability through past pupillary studies to produce pupillary dilation (See Table I). The mental mathematics task was chosen as the primary means of inducing mental cognitive loading because of its information processing demands. The girl-viewing task was chosen as a control against pupillary behavior due solely to arousal. The dot-counting or perceptual motor task was selected as a control against simple sustained effort or continual responding by the subjects. The girl-viewing and perceptual motor tasks did not involve cognitive skills used in the mental mathematics task.

The choice of dependent variables was based, in part, on the desire to evaluate the sensitivity of these measures to pupillary changes.

B. STIMULI AND TASKS

1. Preliminary Tests

Prior to each subject being exposed to the three tasks, preliminary tests for visual shift, light reflex, and accommodation effects

were made to confirm the sensitivity of the experimental equipment based on known results of effects due to visual shift, light reflex and accommodation.

The visual shift test measured the effects on the pupil as the subject viewed various portions of the stimulus slides. A numbered control slide was used during this test (Figure 1). The subject was instructed to fixate first on the number "5" in the center of the slide and then to view each of the other numbers on the slide for a short time in the order of 5-1-2-3-4-5.

The light reflex test measured the effects on the pupil as the subject viewed black or white areas of the stimulus slide. During this test the subject was instructed to view first the white area in the upper left corner of the light reflex control slide (Figure 2), then to view each of the other corners in the order of white (upper left) -- black (upper right) -- white (lower right) -- grey (lower left) -- white (upper left).

The accommodation test measured the pupillary behavior of the subject when he focused on the screen or on an object other than the screen during the experimental session. The control slide used for the visual shift test was first displayed and the subject was instructed to fixate on the number "5" which was 37 inches from the subject's position. After a short period of time, a white paper with a 1/2 inch blue dot centered on it was placed at a distance of 21 inches in front of the subject. He was instructed to fixate on the dot for a short time, then the dot was removed and the subject continued to fixate on "5".

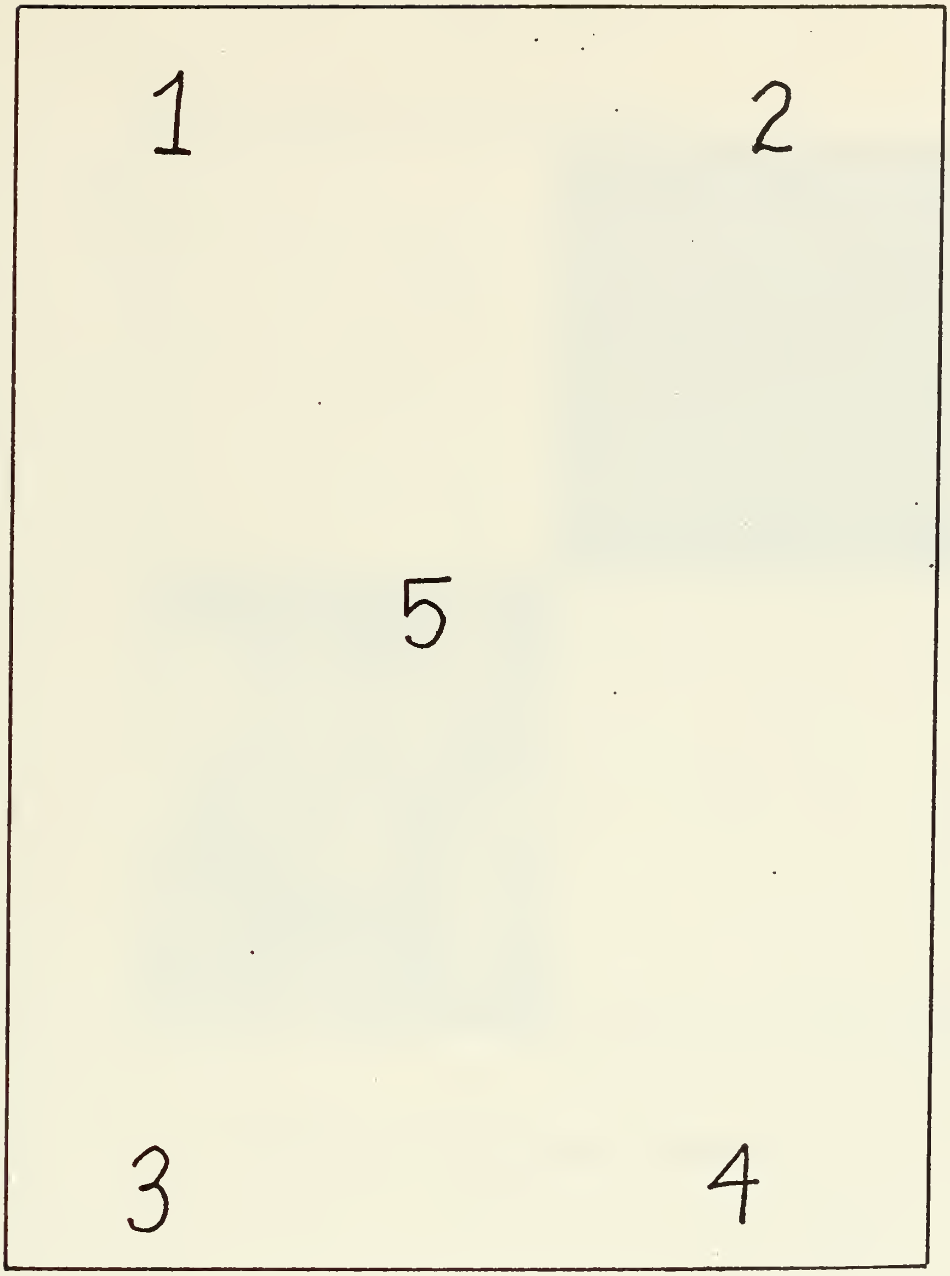


FIGURE 1 - PUPILLARY SHIFT CONTROL SLIDE

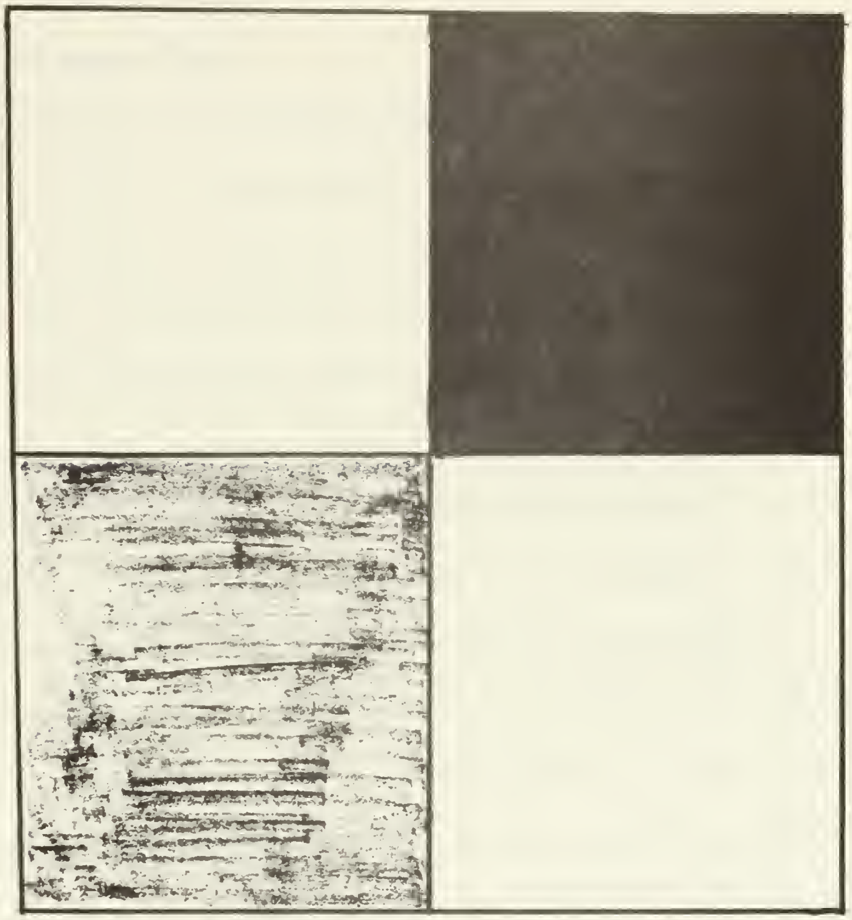


FIGURE 2 - LIGHT REFLEX CONTROL SLIDE

The average duration times of each of these preliminary tests was 90 seconds for both the visual shift and light reflex tests and 45 seconds for the accommodation test.

2. Experimental Tasks

The design of the mental mathematics task differed in duration and procedure from task requirements involving mathematical operations used in past pupillary studies. As a means of imposing an increasing mental load on the subjects, each level of difficulty in this task contained a serial mathematical problem presented to the subject in 10 steps (slides). The subject had to perform each mathematical operation on each slide in his head, carry the answer from each slide to the operation on the next slide, and to continue in this manner until the final slide depicted the last operation and asked for the answer.

Prior to experiencing this task, an introductory slide (Figure 3) was presented to the subject and the experimenter described the procedure to be followed. The subject was then given a practice subtask, which was considered to be easy to perform, and was then given the experimental subtasks. The levels of difficulty for each subtask was defined by the frequency in which the subject encountered one, two, or three-digit numbers in the mathematical operations. The easy subtask contained predominantly single-digit numbers; the moderate subtask had more two-digit numbers with some one-digit numbers; and the difficult subtask introduced a few three-digit numbers. Figure 4 contains each of the subtasks with their accompanying mathematical operations. Facsimiles of the actual slides used are contained in Appendix E.

The arousal task presented a successive display of girl pictures which were categorized into levels of difficulty based on the complexity of objects the subject had to view in each slide. The subject was told

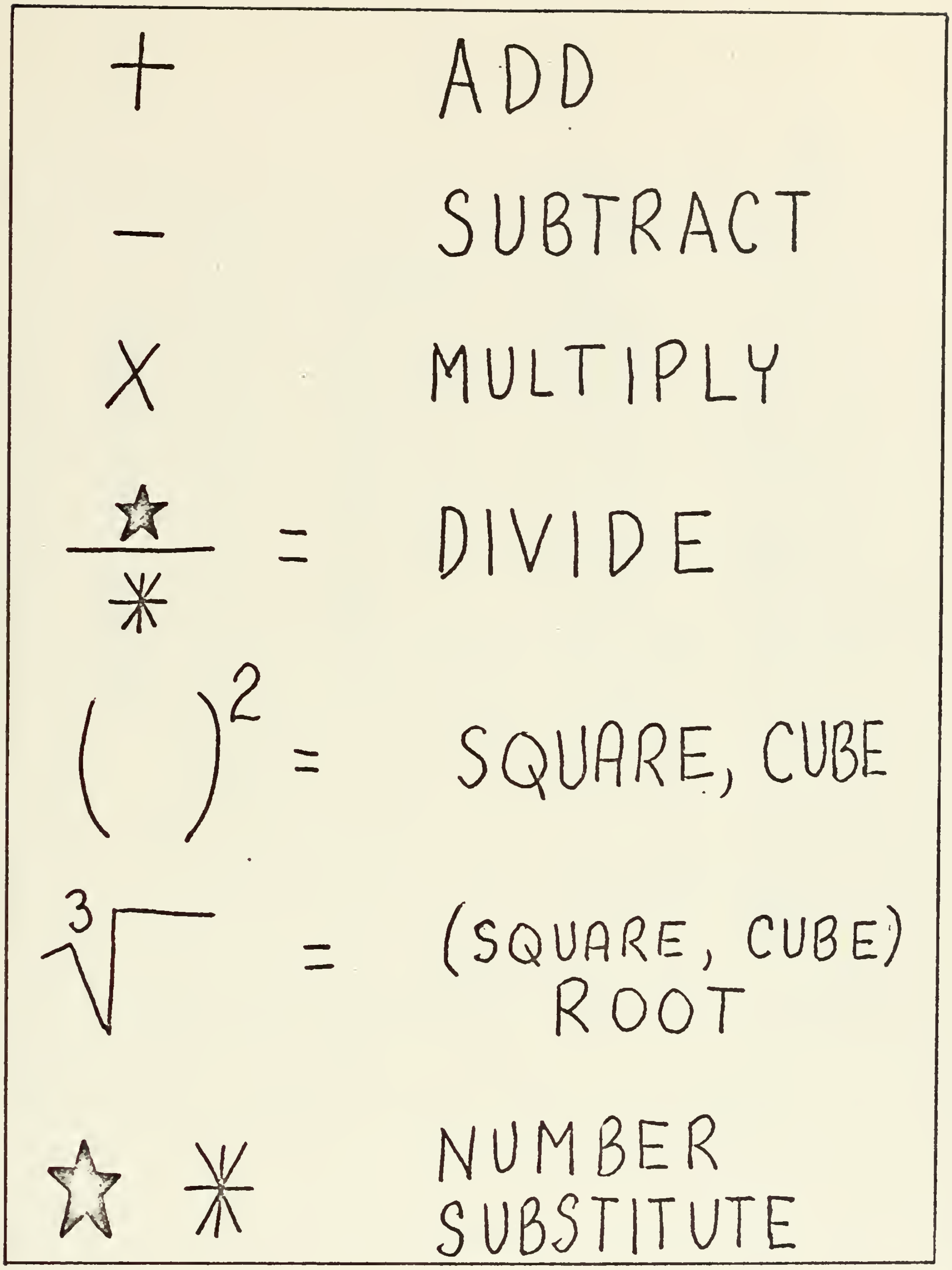


FIGURE 3 - INTRODUCTORY SLIDE TO MENTAL MATHEMATICS TASK

FIGURE 4 - MENTAL MATHEMATICS PROBLEMS

Subtask	Mathematics Problem Sequence
Practice	$\sqrt[2]{4} = (2)$; $(2) + 2 = (4)$; $(4)^2 = (16)$; $(16)/8 = (2)$; $(2) \times 5 = (10)$; $(10) - 9 = (1)$; $(1)^3 = (1)$; $(1) \times 7 = (7)$; $(7) + 2 = (9)$; $\sqrt[2]{(9)} = (3)$
Easy	$10/5 = (2)$; $(2) + 7 = (9)$; $\sqrt[2]{(9)} = (3)$; $(3) \times 4 = (12)$; $(12)/6 = (2)$; $(2)^3 = (8)$; $(8) - 7 = (1)$; $(1) \times 4 = (4)$; $\sqrt[2]{(4)} = (2)$; $(2) + 8 = (10)$
Moderate	$56 + 4 = (60)$; $(60)/5 = (12)$; $(12) \times 3 = (36)$; $\sqrt[2]{(36)} = (6)$; $(6) - 3 = (3)$; $(3)^3 = (27)$; $(27) + 22 = (49)$; $\sqrt[2]{(49)} = (7)$; $(7) \times 9 = (63)$; $(63)/3 = (21)$
Difficult	$15 \times 3 = (45)$; $(45) + 4 = (49)$; $\sqrt[2]{(49)} = (7)$; $(7) + 2 = (9)$; $(9)^2 = (81)$; $(81) - 39 = (42)$; $(42)/3 = (14)$; $(14) + 130 = (144)$; $\sqrt[2]{(144)} = (12)$; $(12) \times 9 = (108)$

Note: The numbers in brackets denote the numbers the subject had to carry in his mind.

that he would be viewing nude and seminude pictures of women extracted from "Playboy" magazine and that he was not required to perform any task other than to scan completely each slide as it was presented. No trial slide was considered necessary for this task. Figure 5 shows examples of slides used during each subtask. The easy subtask stimulus slides contained views of the girls' faces with limited exposure of the rest of their bodies. The backgrounds in these slides were plain and contained no other objects. The stimulus slides used in the moderate and difficult subtasks revealed more of the nude model's body. There was uniform background clutter in the moderate subtask and heterogeneous background clutter in the difficult task.

The perceptual motor task was a dot-counting task in which levels of difficulty were achieved by introducing more dots and more symbols (other than dots) of varying patterns in the slides. The subject was instructed to count only the dots he viewed in each slide by means of activating a hand-held button-press. The button-press was connected to the pupillometer chart recorder. As the subject counted the dots on the slides, he depressed the button and for each dot counted, a mark was placed in the left margin of the chart. He was told to use any search technique in locating the dots but was to press the button only at the instant he viewed a dot. A practice slide is shown in Figure 6. The easy stimulus slides only contained dots varying from 4 to 12 dots on each slide. The moderate subtask stimulus slides contained 7 to 15 dots interspersed with only one other symbol (stars, triangles or squares). The difficult subtask stimulus slides contained 10 to 19 dots interspersed with combinations of the three other symbols. Thus, as the level of difficulty increased, the number of dots and other background symbols pictured on the slides also

FIGURE 5 - EXAMPLES OF AROUSAL TASK SLIDES

EXAMPLE OF EASY SUBTASK SLIDE IN AROUSAL TASK

EXAMPLE OF MODERATE SUBTASK SLIDE IN AROUSAL TASK
(Note more background than in Easy Slide)

EXAMPLE OF DIFFICULT SUBTASK SLIDE IN AROUSAL TASK
(Note more background information and more exposure of nude)

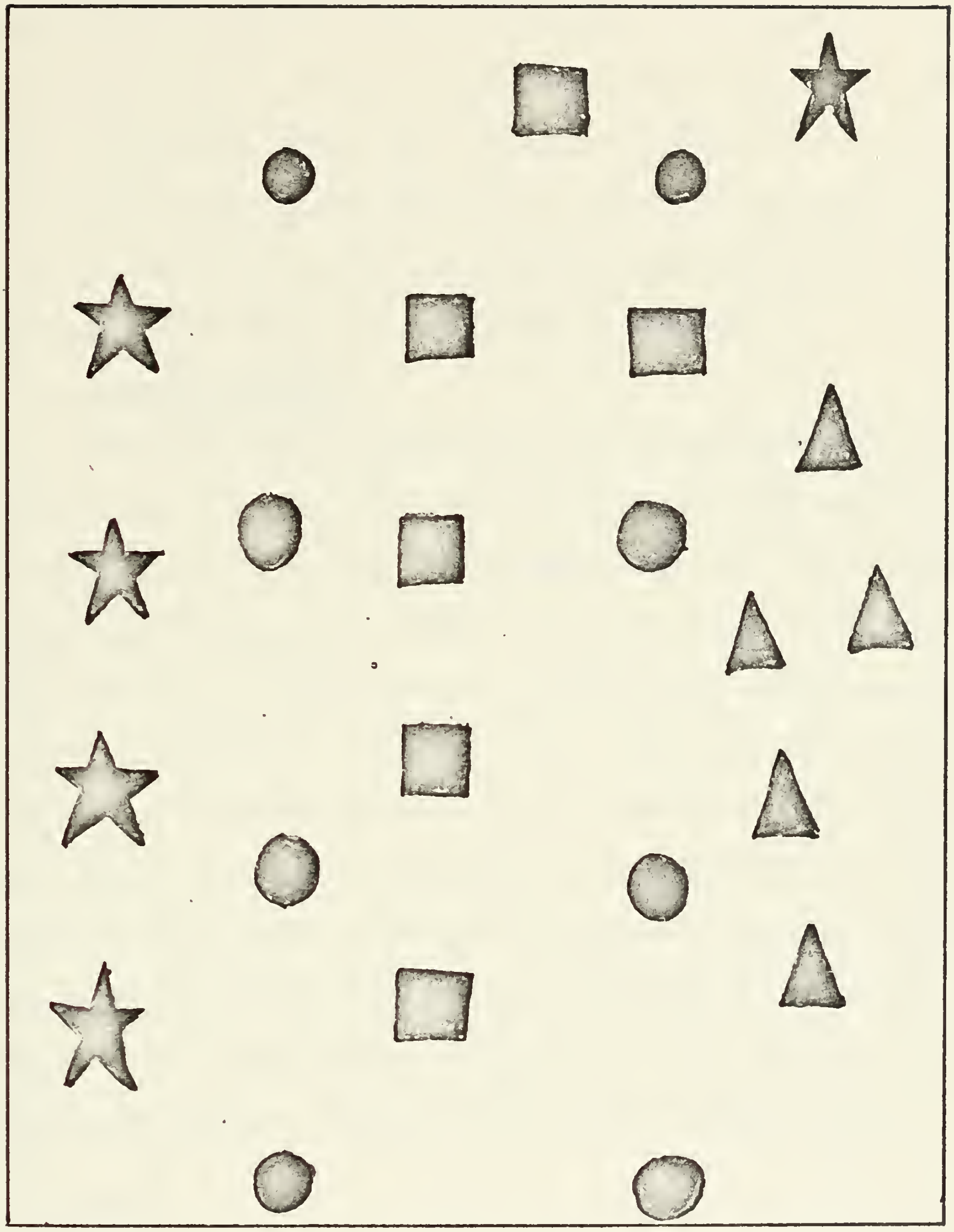


FIGURE 6 - PRACTICE SLIDE OF PERCEPTUAL MOTOR TASK

increased. Facsmiles of the actual slides used in this task are contained in Appendix E.

The exposure time for each slide in any task was 3 seconds with an interval of 4 seconds between each slide. All subtasks for each of the three tasks lasted 66 seconds from presentation of the first slide to withdrawal of the last. Subtasks consisted of 10 slides each and 30 slides made up a complete task. The slides were randomly placed in each subtask sequence for the arousal and perceptual motor tasks. Each slide presentation will be referred to as a trial.

3. Dependent Measures

The critical measurements used in this experiment were derived from the chart record provided by the pupillometer used in this study. The baseline pupil level was a measurement made prior to each subtask and preliminary test as the subject viewed the visual-shift control slide (Figure 1). Latency times to peak pupillary change were recorded for each slide exposure during the tasks. Since the chart record was divided into 0.2 second intervals and the experimenter recorded the exact times of exposure of each slide in the right margin of this record, it was possible to measure the elapsed times until the peak pupil diameters were achieved for each subject during each slide exposure. The latency during the perceptual motor task as the button was depressed for the first dot counted was similarly recorded.

C. SUBJECTS

The subjects were 25 male officer students at the U.S. Naval Postgraduate School who served as subjects on a voluntary basis. All students were enrolled in the Operations Analysis curriculum. Twenty-one were career military officers in the Army, Navy, or Coast Guard

and four were Army or Navy allied officers from Viet-Nam, Thailand or Korea. Their ages ranged from 25 to 39 with an average age of 29 years. Of the 25 subjects tested, 12 wore glasses anywhere from 10-100 percent of each day. When these subjects were placed into the head holder of the pupillometer and a control slide was placed on the screen, 10 of these subjects were American officers who were able to view the screen well enough without glasses being worn and the remaining 2 subjects were Allied officers whc were tested while wearing glasses. None of the subjects were color blind, and none had any history of serious head or eye injuries and anisocoria. All subjects appeared to be alert and were eager to participate in the experiment. The subjects were tentatively divided into three groups, and the same data was collected for each group. The three groups were: 1) allied -- 4 foreign officers, 2) glasses -- 10 American officers, and 3) nonglasses -- 11 American officers. This was done to analyze the possibility that the pupillary response of these groups might differ.

D. SETTING

Experimentation was conducted in the Human Engineering Laboratory of the Naval Postgraduate School. All experiments were conducted in the laboratory with lighting, temperature, noise level, and room arrangement being similar at each experimental session. The entire apparatus used in the experiment was situated in a corner of the laboratory with curtains shielding the corner from all visual distractions. These curtains slightly reduced the level of illumination.

E. APPARATUS

The apparatus consisted of a Space Sciences Incorporated Model 830 TV Pupillometer and a Lafayette Instrument Company Random Access Projection Tachistoscope System (Appendix A).

The TV Pupillometer is composed of a closed circuit television system and a signal processor, which provide continuous observation of the subject's eye. A multipurpose mounting is used for training the television camera onto the subject's left eye while a near infrared illumination source provides a contrast of the subject's pupil with the iris. Associated with this mount is a vertically adjustable chin rest and forehead restraint which were necessary in restricting the subject's head movements during the experimental session. A black-and-white picture of the subject's pupil and iris was presented on the control panel television monitor screen. This picture enabled a signal processor to discriminate between the black pupil and the surrounding white iris and to measure the pupil diameter by means of a white crescent superimposed on the black pupil. Pupil diameter changes expanded or contracted this cresent and these fluctuations were electronically converted into visual and graphical measurements provided on the control panel. A permanent on-line measurement of the pupillary changes was inscribed by a heat pen onto an integrated chart recorder capable of measurements from zero to ten millimeters. While the subject pupil responses were being recorded on the chart paper, the experimenter was able to make notations on the paper relative to which tasks were being presented and the start and finish of each subtask. Calibration of the chart recorder prior to each use of the pupillometer was effected

by means of a 4mm test dot placed on the forehead restraint and aligned in front of the television camera and infrared illuminator.

The Lafayette Random Access Projection Tachistocope control panel was used in conjunction with a Kodak Carousel 960 Projector and a rear projection viewing screen device to present 35mm stimulus slides for viewing by the subjects in the order and time sequence desired by the experimenter. An 8-channel paper tape reader on the control panel advanced the slides for viewing by relaying electronic commands to the slide projector. A binary code enabled the experimenter to punch onto the paper tape the order in which the slides were to be viewed. A timer on the panel permitted the desired slide exposure and interval times to be manually set. The projector was located 13 inches from the mirror located in the back of the screen device. An iris located on the lens of the projector was adjusted to the desired level of light intensity to be projected onto the viewing screen. The projector and screen device were elevated 8 inches above the table top for proper viewing of the slides by the subjects while they were positioned in the chin rest and forehead restraint. The slide images were centered on the viewing screen.

F. INSTRUCTIONS

Subjects were briefed on the general nature of the experiment prior to attending their individual experimental session and were instructed not to form any preconceived ideas as to the functioning of their pupil. Upon entering the laboratory, subjects were asked to read two pages of experimental instructions (Appendix B) while seated in the testing area. They were then briefed by the experimenter on the general operation of the apparatus and the importance of limiting their head movements when

positioned in the chin rest and forehead restraint. This briefing period provided an interval for the adaptation of the subject's eyes to the illumination level. It also served as an interval for stabilization or alleviation of anxiety-provoked dilations due to apprehension about the equipment. The experimenter deferred any inquiries about the experimental stimuli and expected results until the end of the testing session.

G. STIMULI PRESENTATION ORDER

As a means of avoiding progressive errors due to learning, boredom, fatigue, anxiety or other nuisance errors which might confound the experimental results, the order of presentation of the subtasks and tasks was permuted so that no subject received exactly the same order of tasks and subtasks (See Appendix D). Permutation of the order of presentation also permitted the evaluation of order effects for subtask difficulty.

H. TESTING PROCEDURE

Upon entering the laboratory, subjects were given a set of instructions (Appendix B) to read while seated near the experimental apparatus. They were then briefed by the experimenter on the general operation and characteristics of the pupillometric and tachistoscopic systems. The subjects were then given the experimental data sheet (Appendix C) and asked only to look at and answer the questions regarding color blindness, wearing of glasses and frequency of use, age, and history of head and eye injuries.

When the subject felt he sufficiently understood the instructions, he was asked to place his head in the chin rest and keep his head against the forehead retainer. A control slide (Figure 1) was placed on the screen and the subject was asked to fixate on the number "5" in the center

of the screen. Vertical adjustments to the head mount, camera and subject's seat were made to make each subject as comfortable as possible throughout the experimental session. The TV camera and near infrared illumination source were then adjusted to obtain a picture of the subject's left eye. This would allow the proper discrimination necessary for accurate and responsive electronic measurements.

Once these necessary adjustments were made, the subject was given the three preliminary tests in the order: 1) visual-shift, 2) accommodation, and 3) light reflex.

Following these preliminary measurements of the subject's pupillary activity, he was introduced to each of the experimental tasks in the sequence that was assigned to him. The experimenter introduced the subjects to the mental mathematical task by first exhibiting a slide listing the symbols for the mathematical operators to be employed in the slides for each subtask (Figure 3). The first four of the 10 slides in the trial sequence were individually exposed to the subject to clarify further the task procedure. The subject was instructed to give only the answer for each subtask problem (Figure 4) when the experimenter requested it at the end of the sequence. The experimenter did not divulge the correctness of each answer. The subject was told that if he lost the answer from a previous operation he was quickly to estimate the missing number and to continue working the problem. The subject was then given the complete trial sequence and each of the succeeding subtasks.

The experimenter introduced the subject to the arousal and perceptual motor tasks in much this same manner with a trial slide being introduced only in the latter task. In this task, he was also instructed to use any search technique and that dots viewed as the slide disappeared from the screen could also be counted.

Light intensity was controlled for all slides by means of measurements with a Norwood photographic light meter and by adjustments of the iris on the projector lens.

The subject was asked to shut his eyes between each subtask as the tachistoscopic system presented a blank slide with each resetting of the slide sequence. The subject was allowed to relax and view the blank screen between trials while the experimenter arranged the tachistoscope for the next task. A check of the subject's eye measurement was conducted prior to each task and necessary adjustments were made. Once testing had begun for each task, no further adjustments of the pupillometer were made.

Auditory stimulation during testing was held to the sounds of the chart recorder, external marker, tachistoscope control panel, and slide projector. During testing, the experimenter recorded, by means of depressing the external marker, the time and duration of exposure of each slide viewed by the subject.

After completing all three tasks and prior to revealing the purpose of the experiment, subjects were asked to answer the questions at the end of the experimental data sheet relating to blurring of their vision, task difficulty, and critique of the experiment.

The experimental procedure was continuous and lasted approximately 50 minutes per subject with 35 minutes spent for adjustment and measurement of pupillary changes.

IV. RESULTS

A. EXPLANATION OF EXPERIMENTAL MEASUREMENTS

The following measurements were extracted from the graphical output of the pupillometer: 1) baseline pupil level, 2) absolute peak pupil diameter (in millimeters), 3) percentage change of peak pupil diameter, 4) minimum pupil diameter (in millimeters), 5) percentage change of minimum pupil diameter, 6) latency time to peak pupillary change (in seconds), 7) blink rates (blinks per second), and 8) perceptual motor task button-press latency times (in seconds).

The baseline pupil level is a measure of the relatively stable level of the subject's pupil diameter while looking at a control slide. Calculation of this measurement was made by averaging the peak and minimum pupil diameters achieved while each subject viewed the control slide. A 12% average maximum deviation from the baseline pupil level was experienced for all subjects during each nontreatment (control) period.

The absolute peak pupil diameter is the greatest pupillary dilation the subject experienced while viewing each slide or other stimulus for the designated time period. The percentage change of peak pupil diameter is calculated by use of the equation:

$$\text{Percentage Change} = \frac{\text{Peak Pupil Diameter} - \text{Baseline Pupil Level}}{\text{Baseline Pupil Level}} \times 100$$

The minimum pupil diameter is the greatest pupillary contraction or lowest pupil diameter measurement recorded while the subject was exposed to a slide or other stimulus. This was the most difficult measurement to make as eye blinking was allowed and occasionally interfered with this measurement. Eye blinking did not give the same interference for the peak pupil diameter measurement as little blinking occurred during the instant of pupillary peaking and if blinking did occur, the pupil diameter continued to be stable during the peaking period.

The percentage change of minimum pupil diameter is calculated by use of the equation:

$$\text{Percentage Change} = \frac{\text{minimum pupil diameter} - \text{baseline pupil diameter}}{\text{baseline pupil diameter}} \times 100$$

Latency time to peak pupillary change was the elapsed time until the peak pupil diameter was achieved during each slide exposure.

Blink rates were calculated for each subtask and preliminary test to which the subjects were exposed. The number of eye blinks for each subject during each activity divided by total time for the activity resulted in this measurement.

Button-press latency during the perceptual motor task was the time which elapsed from the moment the slide was displayed to the first dot counted, i.e. first button-press.

B. PRELIMINARY TESTS

Tables II-IV reflect the results of the preliminary tests. Only three measures were extracted from this period in order to ascertain the

Stimulus Number*	5	1		2		3		4		5		
Group \ Measurement	Base Pupil Diameter (mm)	Peak Diameter (mm)	% of Peak Change	Peak Diameter (mm)	% of Peak Change	Peak Diameter (mm)	% of Peak Change	Peak Diameter (mm)	P% of Peak Change	Peak Diameter (mm)	% of Peak Change	Blink Rate Change (blinks/sec.)
Allied	3.3	3.7	12.4	4.0	21.2	2.9	- 8.8	3.1	-6.3	3.3	0	0.25
Glasses	3.2	3.6	12.5	3.5	10.7	3.0	- 6.7	3.0	-6.7	3.0	-6.7	0.22
Nonglasses	3.4	3.4	0	3.7	8.8	2.9	-14.7	3.2	-5.7	3.1	-9.7	0.24
Overall	3.3	3.5	8.1	3.7	11.2	2.9	- 8.8	3.1	-6.3	3.1	-6.1	0.23

*See Figure 1

TABLE II - PERCENTAGE CHANGE IN PEAK PUPIL DIAMETER DURING VISUAL SHIFT TEST

Stimulus * Color	White UL		Black UR		White LR		Grey LL		White UL		
Measurement / Group	Base Pupil Diameter (mm)	Peak Diameter (mm)	Peak Dia. (mm)	% of Peak Change	Peak Diameter (mm)	% of Peak Change	Peak Diameter (mm)	% of Peak Change	Peak Diameter (mm)	% of Peak Change	Blink Rate (blinks/sec)
Allied	3.5	3.4	4.0	17.7	3.6	5.9	3.4	0	3.7	8.8	0.28
Glasses	2.9	3.2	3.5	9.4	3.0	-6.3	2.9	-9.4	3.1	-3.1	0.19
Nonglasses	3.4	3.3	3.9	18.2	3.0	-9.1	3.1	-6.1	3.4	3.0	0.24
Overall	3.3	3.3	3.7	12.1	3.2	-3.0	3.1	-6.1	3.4	3.0	0.23

* See Figure 2

<u>Legend</u>: UL - Upper Left Corner of Slide
UR - Upper Right Corner of Slide
LR - Lower Right Corner of Slide
LL - Lower Left Corner of Slide

TABLE III - PERCENTAGE CHANGE IN PEAK PUPIL DIAMETER DURING LIGHT REFLEX TEST

Stimulus Object	#5*	Dot**		#5		
Measurement / Group	Base Pupil Diameter (mm)	Peak Pupil Diameter (mm)	% of Peak Change	Peak Pupil Diameter (mm)	% of Peak Change	Blink Rate (Blinks /sec)
Allied	3.5	3.0	14.3	3.4	-2.9	0.36
Glasses	2.9	3.5	20.7	3.0	3.5	0.24
Nonglasses	3.2	4.0	25.0	3.3	3.1	0.30
Overall	3.2	3.6	12.5	3.2	0	0.29

* Screen Distance - 37 inches

** Dot Distance - 21 inches

TABLE IV - PERCENTAGE CHANGE IN PEAK PUPIL DIAMETER DURING ACCOMMODATION TEST

extent of pupillary changes due to the subject's viewing specific portions of the screen, viewing different shadings on the screen, and viewing an object which was less than the screen distance away from his position. The blink rate measurement was introduced as a control level against which the rates reflected in later analyses could be compared.

The results of the preliminary tests are shown in Tables II-IV. An analysis of variance for a treatment by subjects randomized block design was performed on the percentage change in peak pupil diameter measurements for all subjects during the visual-shift and light reflex tests (Kirk, 1968). This analysis for each test disclosed a significant difference ($p < 0.01$) in subject responses when viewing the various portions of the control slides used in these tests. A similar analysis was performed on the accommodation test results disclosing a significant difference ($p < 0.01$) in subject responses when viewing close or distant objects. Blink rates for all tests were constant with an increase in the accommodation test being primarily due to the interruption of the subjects' field of view when the test dot was interjected.

These preliminary tests were introduced for the sole purpose of ascertaining the sensitivity of the experimental equipment and to detect possible adverse effects on subject pupil responses. These analyses confirm the expected effects of light reflex and accommodation on pupillary changes. The visual-shift and light reflex results suggest that the percentage changes in peak pupil diameter were not due solely to looking at the various portions of the screen or the light reflex effect but were due to a prolonged viewing of the stimulus slides associated with these tests. Tables II and III reflect a non-return at the end of each test to the base pupil diameter which the

subject possessed at the start of the tests. The light reflex effect is, in part, the cause for this difference as shown in Table III, however, the homogeneity of the stimulus numbers in Table II suggest the difference is due to a factor other than possible visual shift effects. The subjects viewed the stimulus slides in each test for 90 seconds with approximately 18 seconds being allotted to each stimulus number and color. This prolonged viewing of each stimulus number and color produced a change in subject pupil diameter that was distinct from any visual shift or light reflex effects. As the subject viewed the stimulus slides used during the experiment for only 3 seconds, it is believed that such a prolongation effect would have little influence on subject responses and can therefore be ruled out of the experiment. Pupil response effects due to accommodation can be ruled out of this experiment as the subject viewed all slides while positioned at a constant distance from the screen.

C. SUBJECT GROUPS

The null hypothesis, that no differences existed between the three subject groups, was tested. A Mann-Whitney U-Test was performed on the percentage of change in peak pupil diameter during randomly selected subtasks for each of the compared groups (Brownlee, 1965). The first comparison was between the Allied and American officers resulting in an insignificant difference at the 0.05 level. A further comparison of subjects wearing glasses with those that did not resulted in an insignificant difference at the 0.05 level. The direct difference method for testing the means between paired observations of a different random sample or percentage change in peak pupil diameter was applied

to those same comparative groups resulting in an insignificant difference at the 0.05 level (Ostle, 1963). The results of these two tests support the acceptance of the null hypothesis and the group results can be pooled.

D. EXPERIMENTAL TASKS

Table V shows the base pupil diameters, peak pupil diameters, percentage change in peak pupil diameters, minimum pupil diameters, percentage change in minimum pupil diameters, peak and button-press latency times, and the blink rates for each task and subtask. The purpose for having introduced all of these measurements into this experiment was to achieve a better comparison of the sensitivity of these measurements to the subject responses since little agreement exists among past pupillary studies as to which measures are the better dependent variables.

The peak and minimum pupil diameter and blink rate measurements appear to be nondiscriminating measurements of the tasks and levels of difficulty experienced by the subjects during all three tasks. The more sensitive dependent variables under all treatment combinations were the percentage changes in pupil diameter and peak button-press latency times.

The percentage change in peak pupil dilation for all treatments by blocks of trials is shown in Table VI. The 10 trials in each subtask were grouped into 5 blocks of 2 trials for analysis. Table VII presents the results of a task x level of difficulty x blocks of trials x subjects analysis of variance that was performed on these data. Figures 7 and 8 display the tasks x trials and levels x trials effects on percentage change in peak pupil diameter measurements. The generally insignificant results in this analysis indicate no treatment effects and

TABLE V

SUMMARY OF RESULTS OF EXPERIMENTAL TASKS AND SUBTASKS OVER TRIALS

Task / Measure	Mental Mathematics			Arousal			Perceptual Motor		
Levels (Subtasks)	E	M	D	E	M	D	E	M	D
Base Pupil Diameter(mm)	2.7	2.8	2.8	2.7	2.6	2.8	2.7	2.8	2.7
Peak Pupil Diameter(mm)	3.44	3.69	3.69	3.30	3.24	3.61	3.49	3.73	3.47
Percentage Change in Peak Pupil Diameter	28	32	30	25	29	30	29	35	31
Minimum Pupil Diameter(mm)	2.73	2.91	2.94	2.56	2.50	2.89	2.62	2.79	2.55
Percentage Change in Minimum Pupil Diameter	1	3	4	-5	-4	3	-4	-2	-6
Peak Latency Time (sec)	1.95	2.02	1.99	2.06	2.15	2.15	1.85	1.98	1.96
Button-Press Latency Time (sec)	—	—	—	—	—	—	0.28	0.38	0.48
Blink Rate (blinks/sec)	0.55	0.63	0.62	0.46	0.50	0.47	0.48	0.48	0.50

E - Easy M - Moderate D - Difficult

TABLE VI

PERCENTAGE CHANGE IN PEAK PUPIL DIAMETER FOR ALL TREATMENTS BY BLOCKS OF TRIALS

Task	Level \ Trial Blocks	1	2	3	4	5
Math	E	22.2	28.6	30.2	28.8	30.0
	M	30.7	28.8	29.0	34.0	34.8
	D	28.1	24.7	33.5	36.4	33.0
Arousal	E	22.4	28.0	24.2	29.3	24.3
	M	20.8	30.3	30.7	27.1	28.8
	D	25.0	30.8	28.7	29.9	35.0
Motor	E	28.0	30.7	30.3	34.0	30.6
	M	31.6	34.8	34.7	36.1	30.8
	D	31.1	28.7	27.4	25.6	27.5

E - Easy Subtask

M - Moderate Subtask

D - Difficult Subtask

TABLE VII

ANALYSIS OF VARIANCE OF PERCENTAGE CHANGE IN PEAK PUPIL DIAMETER

Source	df	SS	MS	F	p
Tasks	2	1778.0	889.0	1.32	—
Levels of Difficulty	2	1778.0	889.0	1.32	—
Blocks of Trials	4	444.45	111.1	0.16	—
Subjects	24	52800.8	2200.0	3.26	0.01
Tasks X Levels	4	2462.0	615.5	0.91	—
Tasks X Trials	8	4088.7	511.1	0.76	—
Levels X Trials	8	2488.6	311.1	0.46	—
Tasks X Levels X Trials	16	21414.9	1338.4	1.98	0.05
Error	384	259462.55	675.68		

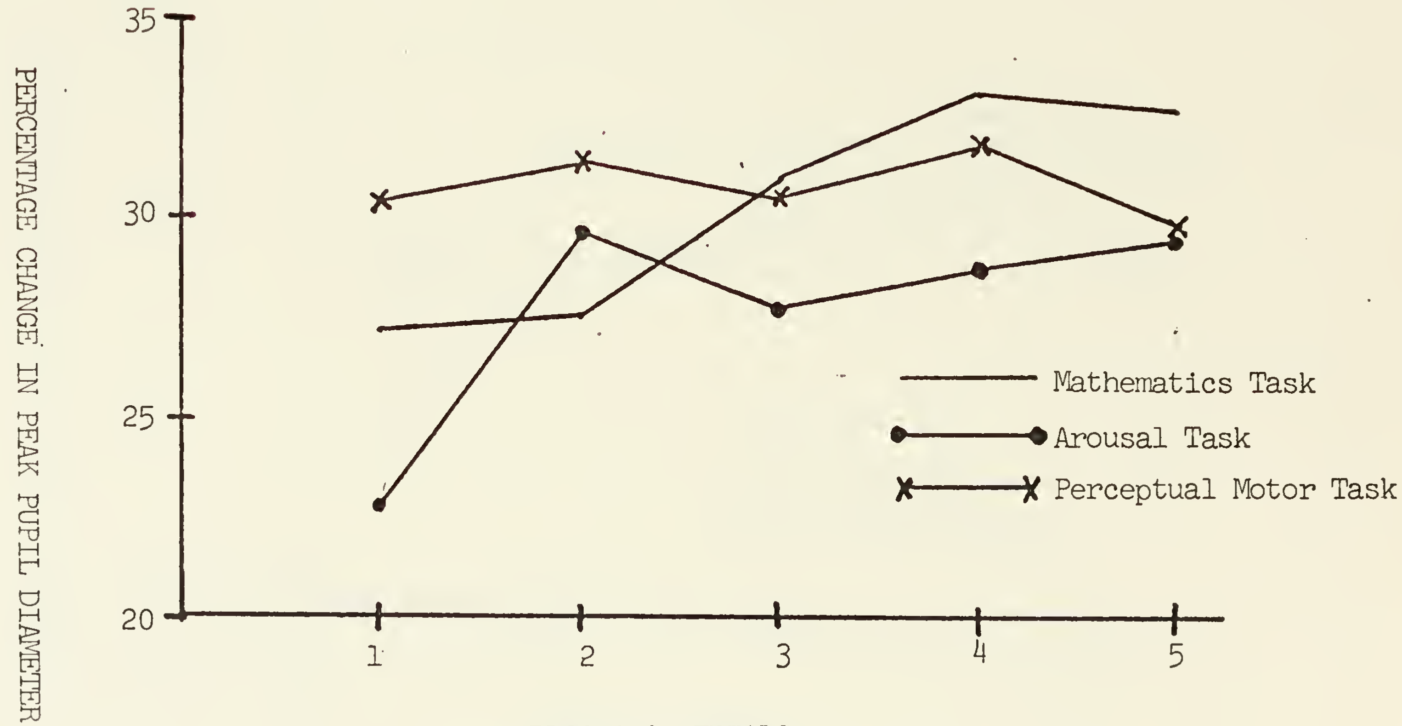


FIGURE 7 - PERCENTAGE CHANGE IN PEAK PUPIL DIAMETER
BY TASKS AND BLOCKS OF TRIALS

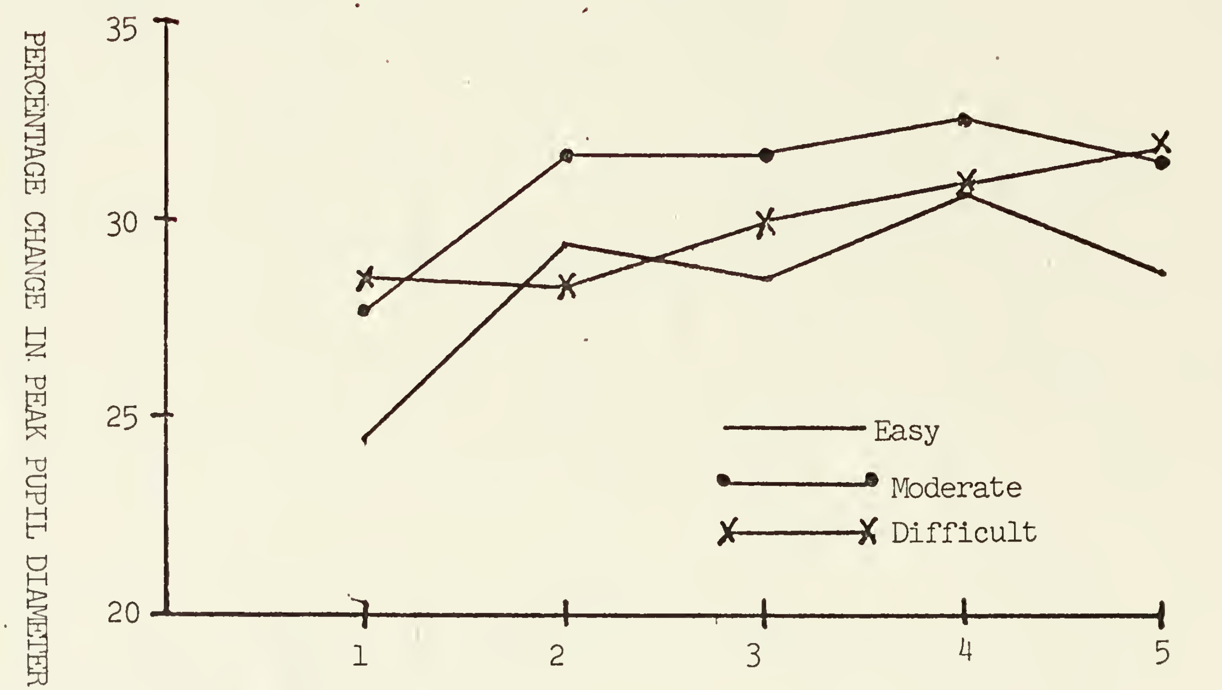


FIGURE 8 - PERCENTAGE CHANGE IN PEAK PUPIL DIAMETER
BY LEVELS AND BLOCKS OF TRIALS

suggests that the same pattern of results would have been obtained by having applied any one of the three tasks to the subjects over the same levels of difficulty.

Table VIII shows the percentage change in minimum pupil diameter for all treatments by blocks of trials. An analysis of variance similar to that applied to the peak pupil diameter was performed on these data with the results shown in Table IX. The number of significant effects in this analysis suggests the greater sensitivity of the minimum pupil change measurements to treatment effects.

Figures 9 and 10 illustrate the extent of the differences between the tasks, levels of difficulty and the blocks of trials as reported in Table IX. The difference between the tasks is reflected in Figure 9 with the mental mathematics task producing a higher overall percentage change suggesting a greater degree of subject mental activity occuring during that task. The slight drop-off experienced by the two control tasks during the last two trials suggests a declination in arousal which may, in part, contribute to the extent of drop-off in the mathematics task. The difference in the levels of difficulty is reflected in Figure 10 with the difficult level achieving a higher percentage minimum pupil change during the final half of the subtask for all tasks suggesting a nonuniform buildup in task difficulty for this subtask over the initial trials. The differences between the blocks of trials is apparent in the curve fluctuations depicted in both Figures 9 and 10.

Figure 11 illustrates the extent of the significant tasks x level interaction found in the analysis. The mental mathematics task produced a curve that is linearly related to the levels of task difficulty. The arousal task produced a curve that corresponds to a curvilinear

TABLE VIII

PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER
FOR ALL TREATMENTS BY BLOCKS OF TRIALS

Task	Level \ Trial Blocks	1	2	3	4	5
Math	E	-1.5	0	0.5	3.0	-0.5
	M	-1.35	4.5	3.0	3.0	6.0
	D	4.0	-2.5	3.5	9.0	4.0
Arousal	E	-6.52	-1.5	-2.5	-4.32	-11.52
	M	-9.52	-3.6	-6.0	-2.8	-1.5
	D	-1.5	2.5	4.5	3.0	6.0
Motor	E	-10.0	-4.0	-4.5	0	-1.0
	M	-4.0	-1.0	2.1	2.0	-0.5
	D	-7.0	-10.5	-9.52	-1.0	-1.5

E - Easy Subtask

M - Moderate Subtask

D - Difficult Subtask

TABLE IX

ANALYSIS OF VARIANCE OF PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER

Source	df	SS	MS	F	p
Tasks	2	8098.0	4049.0	13.2	0.01
Levels of Difficulty	2	3228.0	1614.0	5.2	0.01
Blocks of Trials	4	4997.1	1249.3	4.06	0.01
Subjects	24	14764.8	615.2	2.0	0.01
Tasks X Levels	4	4773.2	1193.3	3.87	0.01
Tasks X Trials	8	348.0	43.5	0.14	——
Levels X Trials	8	1034.2	129.3	0.42	——
Tasks X Levels X Trials	16	9946.5	621.7	2.6	0.01
Error	384	118118.4	307.6		

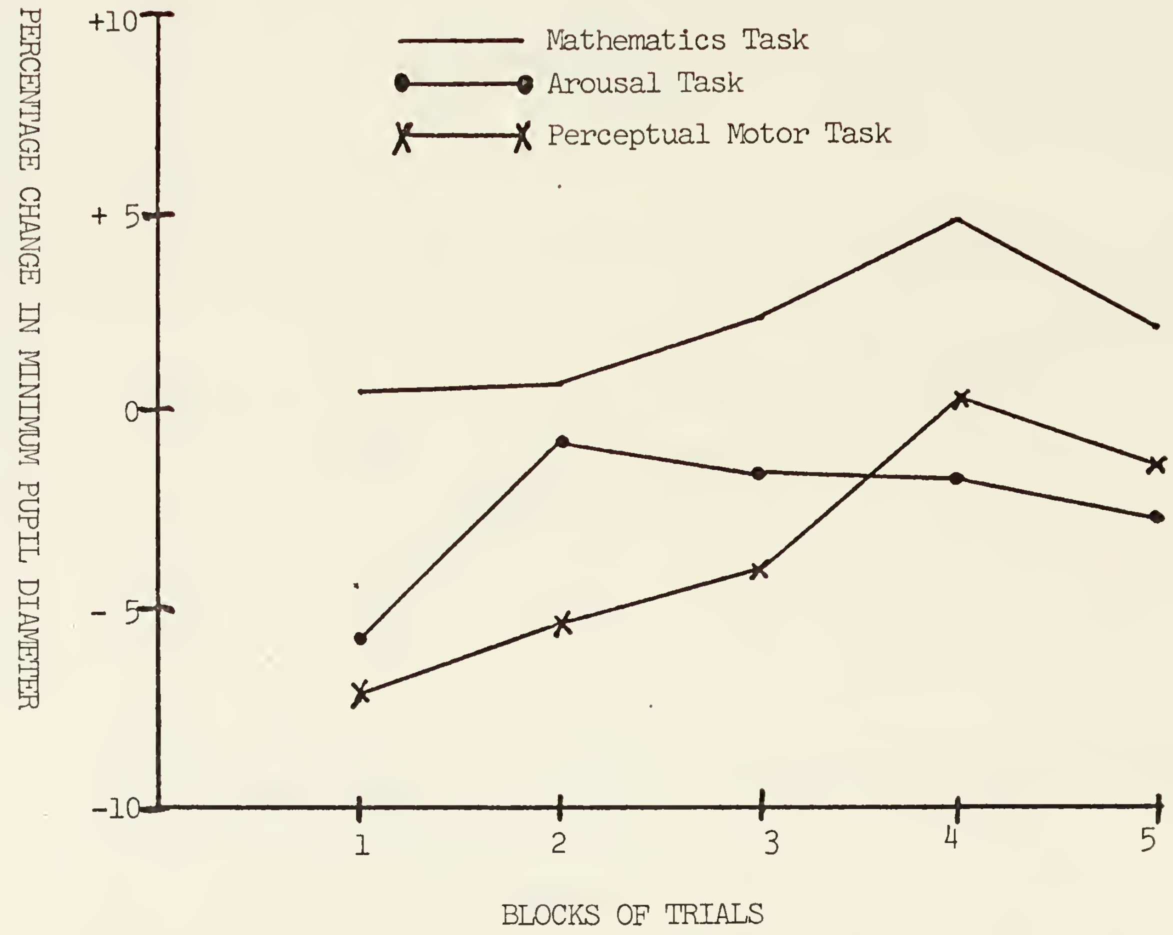


FIGURE 9 - PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER BY TASKS AND BLOCKS OF TRIALS

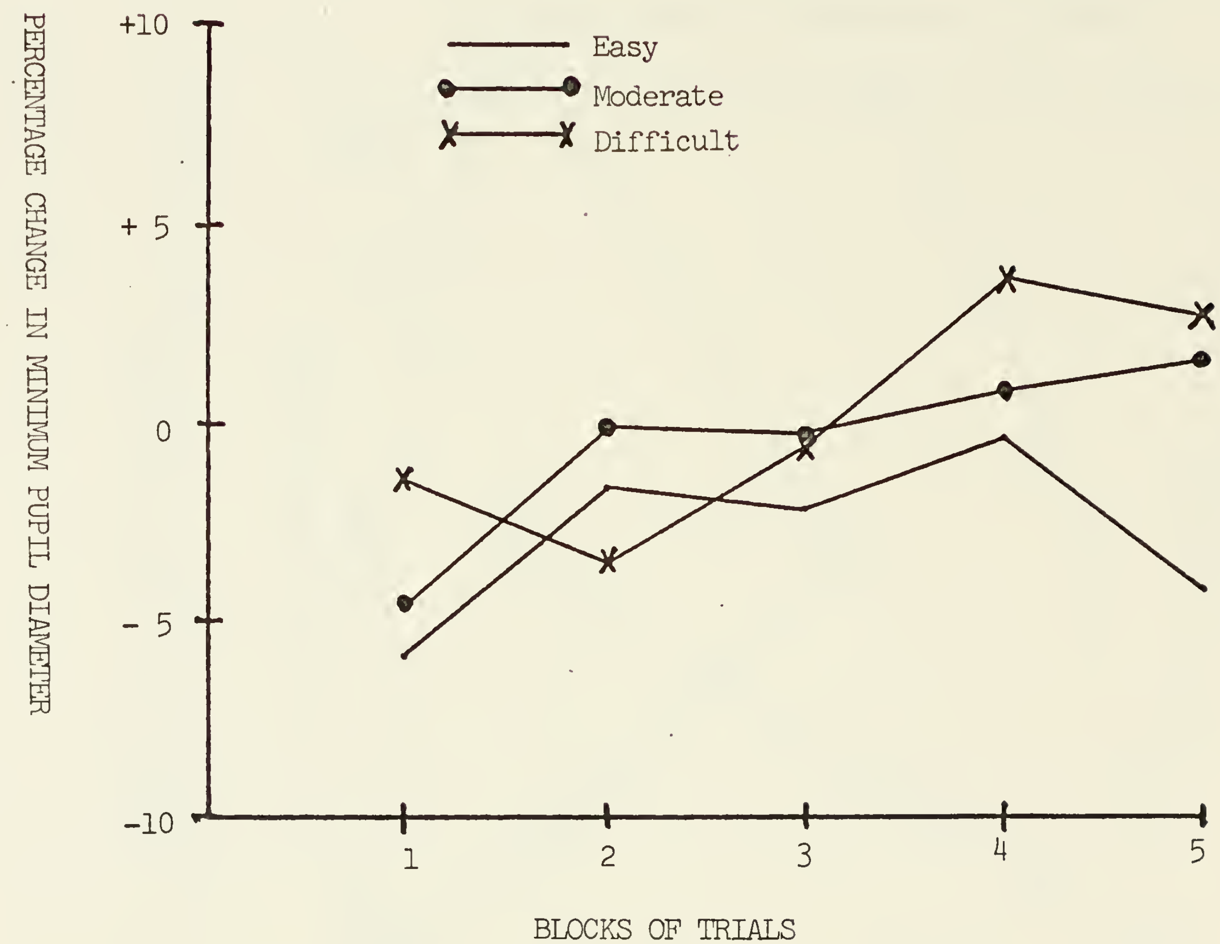


FIGURE 10 - PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER BY LEVELS AND BLOCKS OF TRIALS

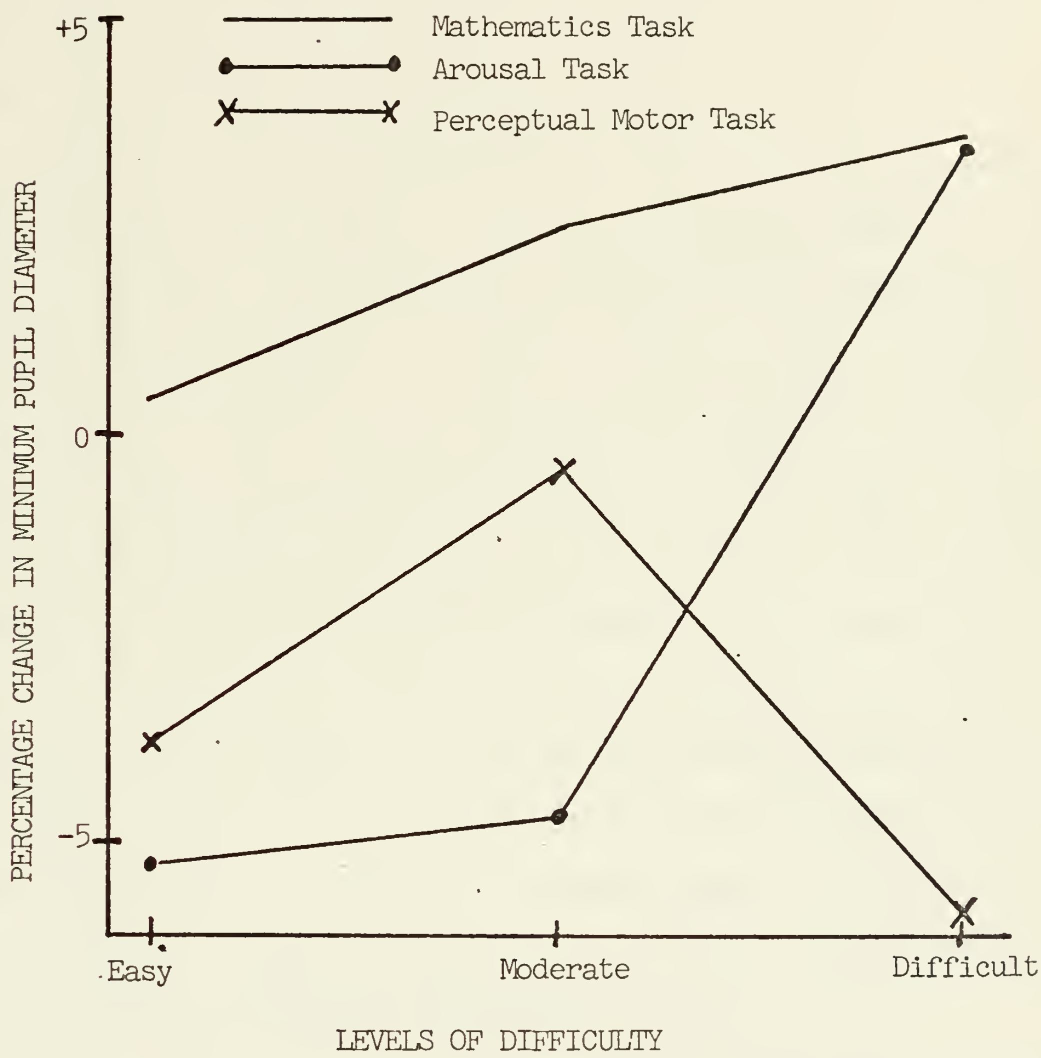


FIGURE 11 - LEVELS X TASKS INTERACTION FOR PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER

increasing function and the perceptual motor task curve is associated with a curvilinear decreasing function. The departure of the perceptual motor curve from the rising curves of the mathematics and arousal tasks over the increasing levels of difficulty suggests a too difficult sub-task having been administered to the subjects which, in turn, produced a drop off in subject interest and effort.

The extent of the significant tasks x levels x trials interaction during the final three blocks of trials is depicted in Figure 12. The curve for the easy level of difficulty for all tasks dropped off during the last trial and suggests a decline in subject interest. The moderate curve rises over the last trials during the mathematics and arousal tasks and slightly declines during the perceptual motor task. The difficult curve is markedly different for each task with a sharp drop off occurring at the end of the mental mathematics task as compared with a slight rise and decline for the arousal and perceptual motor tasks respectively. This departure of the mental mathematics curve during the difficult task from the responses produced by the other tasks when compared with the easy curves for all tasks suggests an effect other than a decline in subject interest. It is possible this drop off is due to the expected cognitive overloading effect.

The peak pupil latency time for all treatments is shown in Table X. Table XI presents the results of an analysis of variance similar to those previously reported for peak and minimum pupil change that was performed on these data. The general insignificant findings in this analysis suggests a lesser sensitivity of this measurement to treatment effects. The curves in Figure 13 depict the lack of significance found in the analysis for the task and task-by-trials effects. Figure 14

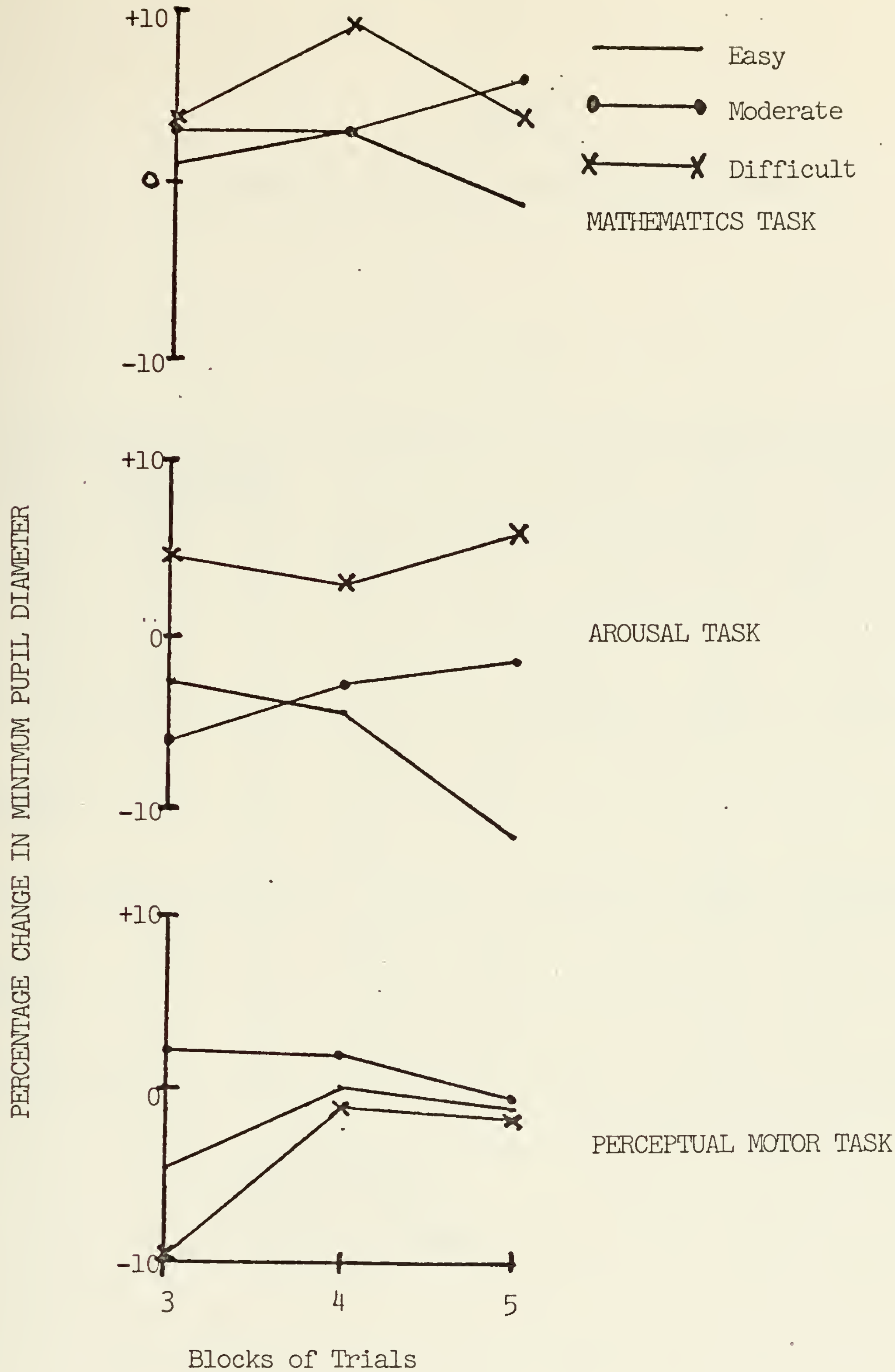


FIGURE 12 - TASKS X LEVELS X TRIALS INTERACTION FOR PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER

TABLE X

PEAK PUPIL LATENCY TIME FOR ALL TREATMENTS

Task	Level \ Trial Blocks	1	2	3	4	5
Math	E	2.1	1.9	2.0	1.8	2.0
	M	2.0	1.4	2.1	1.9	2.1
	D	2.0	1.9	2.2	1.9	2.0
Arousal	E	2.2	2.0	1.8	2.1	2.0
	M	1.8	1.9	1.9	2.1	2.0
	D	2.3	2.2	2.3	1.8	2.2
Motor	E	1.8	1.8	2.0	2.0	1.7
	M	2.0	2.1	2.0	2.0	1.8
	D	1.7	2.1	2.1	2.0	1.9

E - Easy Subtask

M - Moderate Subtask

D - Difficult Subtask

TABLE XI

ANALYSIS OF VARIANCE OF PEAK PUPIL LATENCY TIME

Source	df	SS	MS	F	p
Tasks	2	32.7	16.35	0.58	--
Levels of Difficulty	2	135.1	67.55	2.39	0.10
Blocks of Trials	4	127.3	31.83	1.12	--
Subjects	24	805.2	32.55	1.15	--
Tasks X Levels	4	34.6	8.65	0.31	--
Tasks X Trials	8	24.7	3.01	0.11	--
Levels X Trials	8	111.1	13.89	0.49	--
Tasks X Levels X Trials	16	56.7	3.54	0.13	--
Error	384	10867.2	28.30		

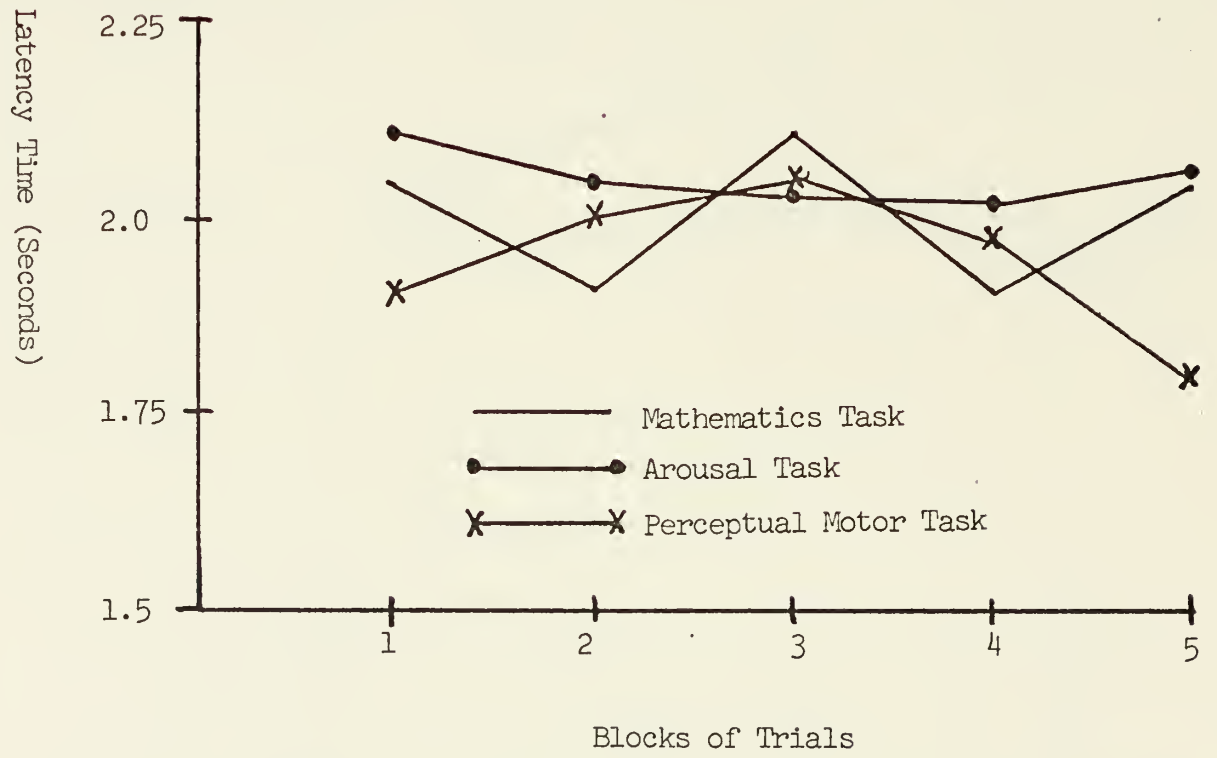


FIGURE 13 - PEAK LATENCY TIME BY TASKS AND BLOCKS OF TRIALS

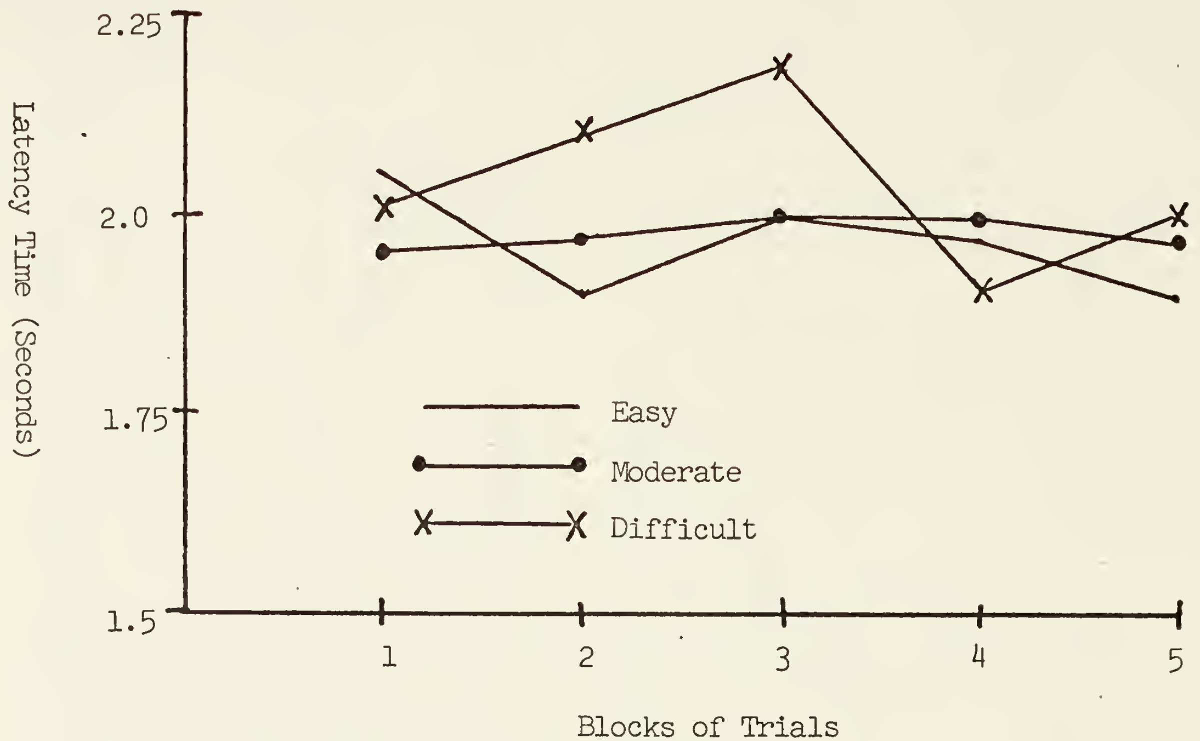


FIGURE 14 - PEAK LATENCY TIME BY LEVELS AND BLOCKS OF TRIALS

depicts the extent of differences between the three levels of difficulty as suggested by the borderline level of significance in the analysis. The difficult level produces a higher latency time suggesting more time was used by subjects in performing the harder problems. The moderate and easy problems, however, show approximately the same latency trends.

Using the data summarized in Table VIII, a task x level of difficulty x blocks of trials x subjects analysis of variance was performed in order further to investigate the influences of the tasks on subject responses during the critical periods of each subtask when a hump in the curves shown in Figures 9 and 10 occurred during trials 3--5 and at the tail of each subtask during trials 4 and 5. The results of these analyses are shown in Tables XII and XIII. The nonsignificance in the tasks x trials and levels x trials interactions suggest the drop off at the end of the curves shown in Figures 9 and 10 are the same for each task and level of difficulty and are possibly due to the same effect.

The foregoing analyses and accompanying figures have suggested a difference in responses for the mental mathematics task. Accordingly, a difficulty-by-trials-by-subjects, randomized blocks analysis of variance was performed on only the responses which occurred during the mental mathematics task (Table VIII). Table XIV presents the results of this analysis. The significant differences occurring in the blocks of trials is shown in Figure 9 by the rise in the percentage change in minimum pupil diameter produced by the middle series of trials.

TABLE XII

ANALYSIS OF VARIANCE OF PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER DURING TRIALS 3-5

Source	df	SS	MS	F	p
Tasks	2	13803.68	6901.84	8.29	0.01
Levels of Difficulty	2	10073.86	5036.93	6.06	0.01
Trials	2	7892.57	3946.29	4.74	0.01
Subjects	24	40961.46	1706.73	2.05	0.01
Tasks X Trials	4	293.08	73.27	0.09	--
Levels X Trials	4	433.96	108.49	0.13	--
Tasks X Levels X Trials	8	18049.68	2256.21	2.71	0.01
Error	192	159849.61	832.55		

TABLE XIII

ANALYSIS OF VARIANCE OF PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER DURING TRIALS 4 AND 5

Source	df	SS	MS	F	p
Tasks	2	19515.83	9757.91	8.15	0.01
Levels of Difficulty	2	14918.23	7459.12	6.23	0.01
Trials	1	8141.57	8141.57	6.80	0.01
Subjects	24	62067.51	2586.15	2.16	0.01
Tasks X Trials	2	379.67	189.84	0.16	--
Levels X Trials	2	516.90	258.45	0.22	--
Tasks X Levels X Trials	4	15421.10	3855.27	3.22	0.01
Error	96	114939.61	1197.29		

TABLE XIV

ANALYSIS OF VARIANCE OF PERCENTAGE CHANGE IN MIMIMUM PUPIL DIAMETER FOR MENTAL MATHEMATICS TASK

Source	df	SS	MS	F	p
Subjects	24	20473.41	853.06		
Blocks of Trials	4	5263.95	1316.00	3.4	0.01
Levels of Difficulty	2	1081.02	540.51	2.37	0.10
Trials X Levels	8	1941.4	242.68	7.35	0.01
Error Trials	96	37129.0	386.76		
Error Levels	48	10928.11	227.67		
Error Trials X Levels	192	6338.05	33.01		
Total	374				

Figure 15 illustrates the extent of the levels of difficulty and highly significant trials x levels interaction during the mental mathematics task. The curve corresponding to the easy level of difficulty is reminiscent of the easy curve shown in Figure 10. The difficult curve is highly bimodal and the moderate curve is slightly bimodal in a direction that is opposite to the direction of the difficult curve. Thus the moderate and difficult levels of difficulty produce results which cancel each other out and arrive at an overall effect which corresponds to that shown in the curve for the easy level of difficulty.

The significant subject and tasks x levels x trials differences reported in Tables VII and IX suggest that some other factor was possibly affecting subject responses to the treatments. It was believed the assignment of different task and subtask sequences to subjects was this factor. Tables XV and XVI show the average percentage change in minimum pupil diameter produced by task and subtask sequences over all treatment combinations. A treatments x treatments x treatments x subjects randomized block factorial analysis of variance was performed on these data with the results shown in Tables XVII and XVIII. The nonsignificant results in these analyses imply that the order in which the tasks and subtasks were taken did not affect the results.

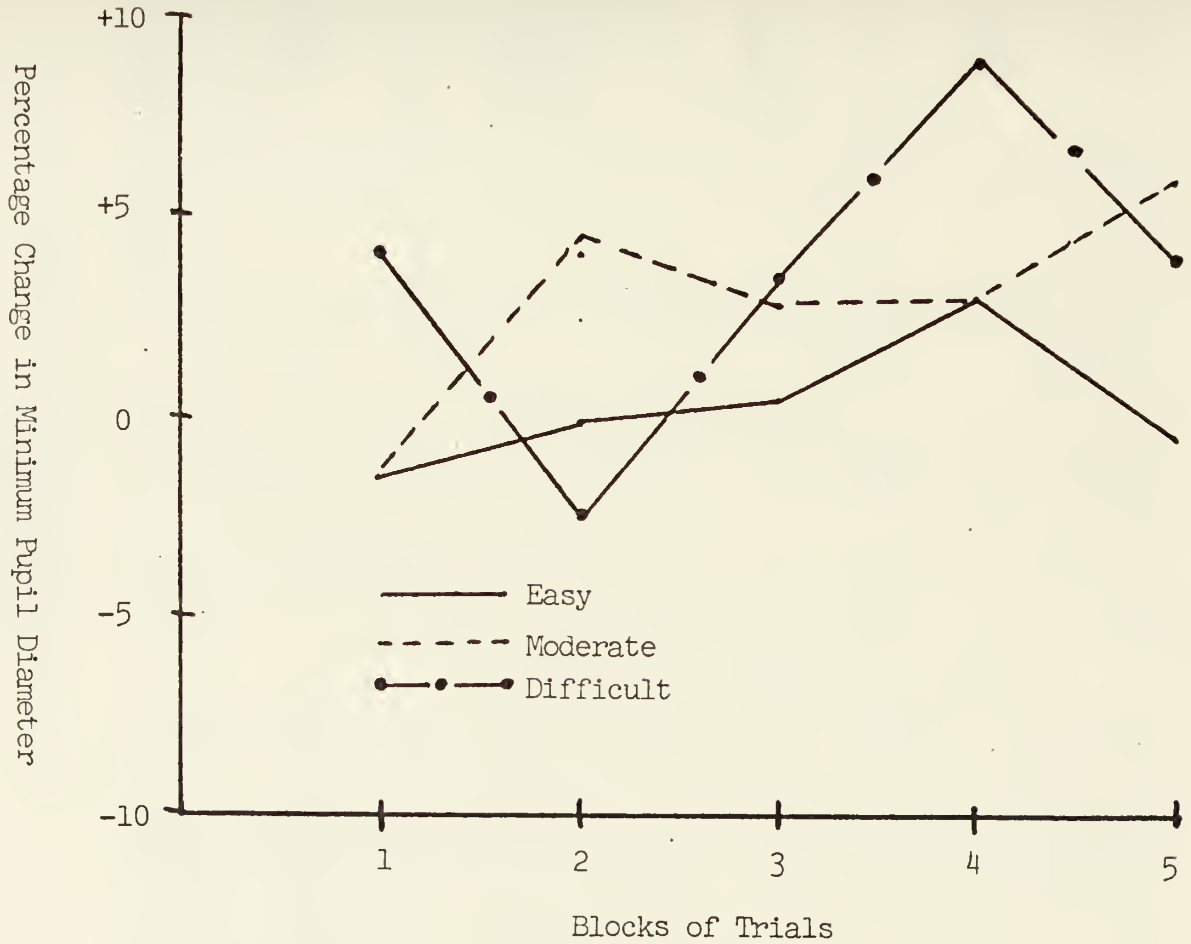


FIGURE 15 - PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER BY TRIALS X LEVELS FOR MATHEMATICS TASK

TABLE XV

AVERAGE PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER PRODUCED BY TASK SEQUENCES OVER ALL TREATMENT COMBINATIONS

Tasks	Levels	A-B-C	B-A-C	B-C-A	A-C-B	C-A-B	C-A-B
Math	E	- 8.0	5.1	- 1.2	-2.5	-1.0	2.4
	M	0	3.2	- 3.1	8.8	-2.0	6.4
	D	- 4.7	7.8	6.5	9.5	3.8	- 0.2
Arousal	E	-12.0	-1.0	- 9.3	-4.3	1.3	- 2.9
	M	4.0	4.0	- 8.5	-7.8	5.1	- 7.4
	D	- 4.0	-1.0	0	9.3	3.5	0.1
Perceptual Motor	E	4.0	-8.0	2.0	-7.8	-9.0	- 6.0
	M	- 6.1	6.2	10.3	-6.1	-1.7	- 8.6
	D	- 9.0	-7.4	1.9	-6.0	-3.5	-14.5
Over All Levels	E	- 5.3	-1.3	- 2.8	-4.8	-2.9	- 2.2
	M	- 0.7	4.5	- 0.4	-1.7	0.4	- 3.2
	D	- 5.9	-0.2	2.8	4.2	1.3	- 4.2
Overall Average		- 3.9	1.0	- 0.1	-0.8	-0.4	- 3.2

Legend: A - Mental Mathematics Task
B - Arousal Task
C - Perceptual Motor Task
E - Easy Level of Difficulty
M - Moderate Level of Difficulty
D - Difficult Level of Difficulty

TABLE XVI

AVERAGE PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER PRODUCED BY SUBTASK SEQUENCES OVER ALL TREATMENT COMBINATIONS

Task	Level	E-M-D	M-D-E	D-M-E	M-E-D	E-D-M	D-E-M
Math	E	- 1.8	1.0	- 2.6	-0.8	5.7	-2.7
	M	7.5	7.8	5.5	0.4	- 1.8	-3.8
	D	9.0	- 0.3	- 2.0	7.4	1.0	8.8
Arousal	E	- 3.0	- 3.8	- 5.7	-3.5	- 0.3	-6.3
	M	- 4.8	- 0.3	- 2.2	0	2.2	-7.0
	D	- 8.8	4.8	- 0.5	-1.0	12.3	2.3
Perceptual Motor	E	- 8.8	-19.0	- 3.7	9.8	- 8.2	3.8
	M	- 3.2	- 9.5	- 4.3	-2.3	7.0	5.7
	D	-12.4	-16.5	-12.0	0.9	- 3.0	1.9
Over All Levels	E	- 4.5	- 7.3	- 4.0	1.8	- 0.9	-1.7
	M	- 0.2	- 0.7	- 0.3	-0.6	2.5	-1.7
	D	- 4.1	- 4.0	- 5.8	2.4	3.4	4.3
Overall Average		- 2.9	- 4.0	- 3.4	1.2	1.7	0.3

Legend: E - Easy Subtask
M - Moderate Subtask
D - Difficult Subtask

TABLE XVII

ANALYSIS OF VARIANCE ON EFFECTS OF TASK SEQUENCING ON PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER

Source	df	SS	MS	F	p
Sequence of Tasks	5	173.60	34.72	0.51	--
Tasks	2	283.36	141.68	2.09	--
Levels of Difficulty	2	103.06	51.53	0.76	--
Sequence X Tasks	10	546.60	54.66	0.81	--
Sequence X Levels	10	219.47	21.95	0.32	--
Tasks X Levels	4	161.48	40.37	0.59	--
Sequence X Tasks X Levels	20	1356.56	67.83		
TOTAL	53				

TABLE XVIII

ANALYSIS OF VARIANCE ON EFFECTS OF SUBTASK SEQUENCING ON PERCENTAGE CHANGE IN MINIMUM PUPIL DIAMETER

Source	df	SS	MS	F	p
Sequence of Subtasks	5	272.83	54.57	0.71	--
Tasks	2	351.35	175.68	2.29	--
Levels of Difficulty	2	73.38	36.69	0.48	--
Sequence X Tasks	10	738.51	73.85	0.96	--
Sequence X Levels	10	181.47	18.15	0.24	--
Tasks X Levels	4	167.80	41.95	0.55	--
Sequence X Tasks X Levels	20	1535.32	76.77		
TOTAL	53				

V. DISCUSSION

The results of this study illustrate the sensitivity of pupillary changes to varying stimuli and suggest its use as an index of cognitive loading on a subject, over long periods of continuous task processing.

During this experiment it was observed that a drop off in the mental mathematics curve occurred toward the end of the subtasks. It was intended that a gradual build-up in the mental load of the subject would occur during the blocks of trials with peak cognitive loading occurring toward the end of the subtask. It was expected that at the time of maximum cognitive loading a sharp decrease in pupil diameter would occur and thereby indicate subject reaction to an overloaded condition. It is possible that as the mental mathematics task was the only task which produced cognitive loading on the subject, the drop off in its curve as shown in Figure 9 corresponded with the attainment of cognitive overloading. However, the analyses performed during the drop off periods for all tasks as reflected in Tables XII and XIII indicated a lack of significant differences between these drop offs.

It is apparent from these results that cognitive tasks do maintain a higher level of percentage change in minimum pupil diameter. This result is indicative of the interest level of the subject with a rising curve corresponding to an increasing interest level and a sharp decline such as shown in Figure 11 being due to the subject "giving up" on a difficult problem. A more detailed analysis of the nature of these drop offs for each task during each level of difficulty during the

final blocks of trials was afforded by Figure 12. It showed that the drop off experienced in all tasks during the easy level of difficulty is indicative of a loss of interest by the subject. It further indicated that the sharp drop off experienced during the mental mathematics task was different from the results found in the other tasks and cannot be attributed to a decline in subject interest. Furthermore, attributing this drop off to the subject "giving up" on the problem and, hence, to an overloaded cognitive condition appears to be reasonable as 4 of the 25 subjects actually missed the most difficult mathematical problem and nearly all subjects gave incorrect responses to the difficult problem in the perceptual motor task.

The results obtained in this experiment did agree with the findings of Bradshaw (1968), Payne (1968), Schaefer (1968), Hess (1965), Hess and Polt (1964), and Polt (1970). In general, the percentage of changes in peak pupil diameter experienced by the subjects in this experiment exceeded the percentage changes reported in these studies. However, this experiment showed that absolute peak diameter and peak percentage change were not as sensitive a measure of subject response as the minimum percentage change in pupil diameter. This study has also shown that peak latency time is also an insensitive measure of the pupillary response and the result obtained in this study fail to support its use as a reliable measure of subject information processing. However, the corresponding increase of this measure with the increasing levels of difficulty as shown in Figure 13 agrees with the results obtained by Bradshaw (1968). The measure of blink rate as a discriminator of task difficulty used in this study and presented in Table V showed inconsistent results for each subtask.

The responses shown in this table are in disagreement with the reports of Drew (1951) and Venables and Martin (1967) who maintain that an inverse relationship exists between blinking and problem difficulty. A more consistent relationship in this regard is reflected in this table for the button-press latency time. These results are in agreement with those found in studies by Simpson (1969) and Colman and Paivio (1970). It is suggested that further examination of these measures in other pupillary experiments is in order.

This study has further indicated a more positive percentage change in minimum pupil diameter with respect to the baseline level being achieved by a cognitive loading task than by an arousal and perceptual motor task. This result corresponds to similar relationships obtained by past studies already cited which employed the absolute pupil diameter and the percentage change in peak pupil diameter as measures of subject responses.

Figures 9 and 10 indicate that the blocks of trials produced a gradual rising of the curves for the tasks and levels of difficulty over the blocks. Figures 9 and 15 also suggest that increasing levels of difficulty produced increases in the level of percentage change in minimum pupil diameter for the subjects tested.

The results of this experiment further indicate that the effects due to tasks x trials and levels x trials interactions were nonsignificant with the curves in each case being approximately the same. The curves rose over the initial blocks of trials thereby producing a more positive percentage change in minimum pupil diameter and a drop off occurred during the last trial.

The effect due to the tasks x levels interaction as shown in Figure 11 was pronounced with the mental mathematics and arousal tasks producing a more positive percentage change in minimum pupil diameter over an increase in the level of difficulty and the perceptual motor task produced an abrupt drop off at the difficult level. This drop off underlines the necessity of the experimenter in carefully choosing a problem or task which is not unreasonably difficult for his subject.

The post-experiment debriefing conducted by the experimenter with each subject revealed no noticeable blurring of their vision during the session which contradicts Kahneman and Beatty's (1966) findings but is supported by Mendelski's study (1970). Further examination of this effect is in order.

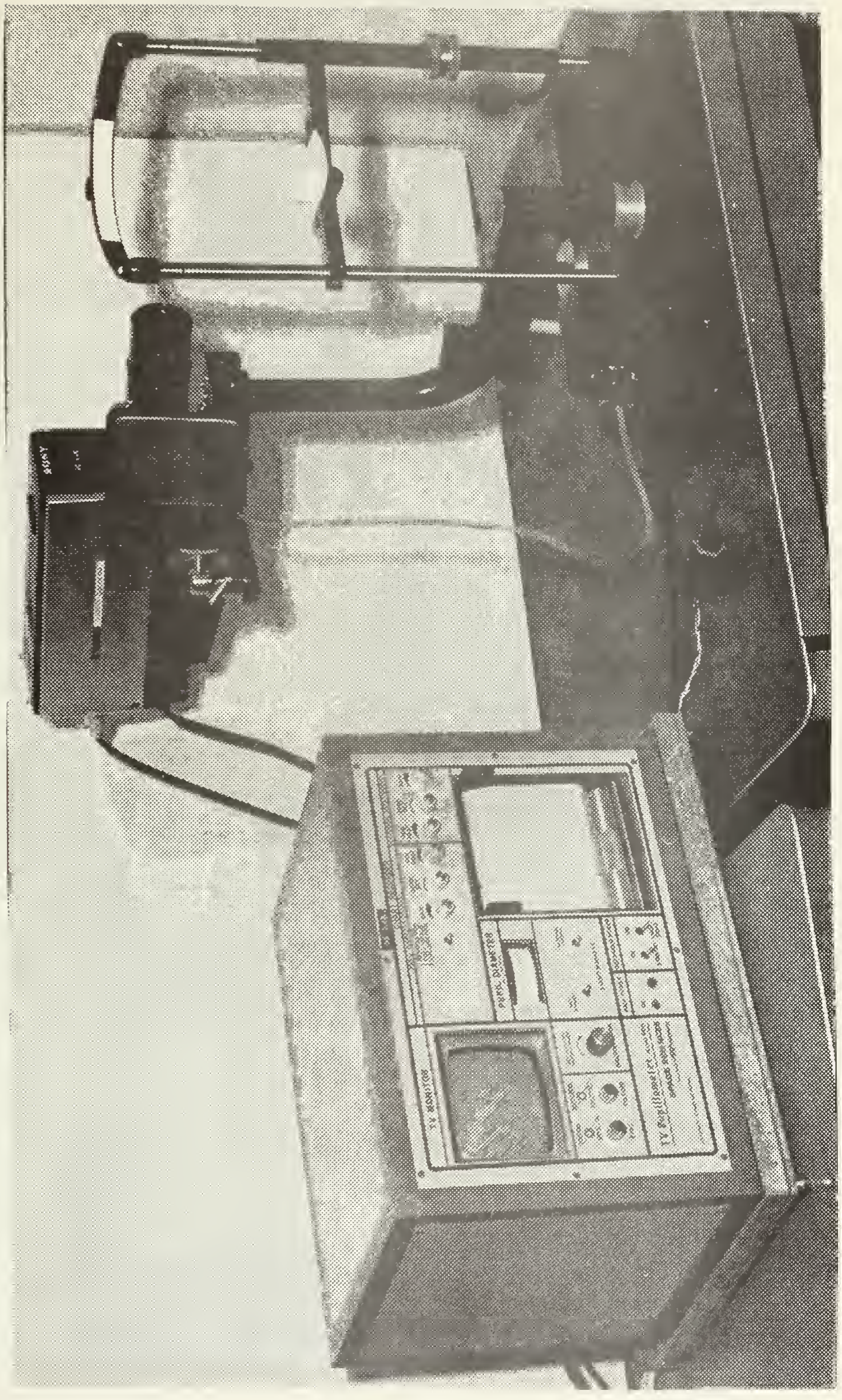
VI. CONCLUSION

Support of the hypothesis that a diminishing pupillary dilation during long-term cognitive loading is an indicator of mental overloading was clearly acquired in this experiment. When compared with two other control tasks that did not produce mental overloading but did reflect subject responses due to arousal and perceptual motor activity, the mental mathematics task showed a definite drop off from the acquired pupil dilation level when peak information processing or overloading was achieved.

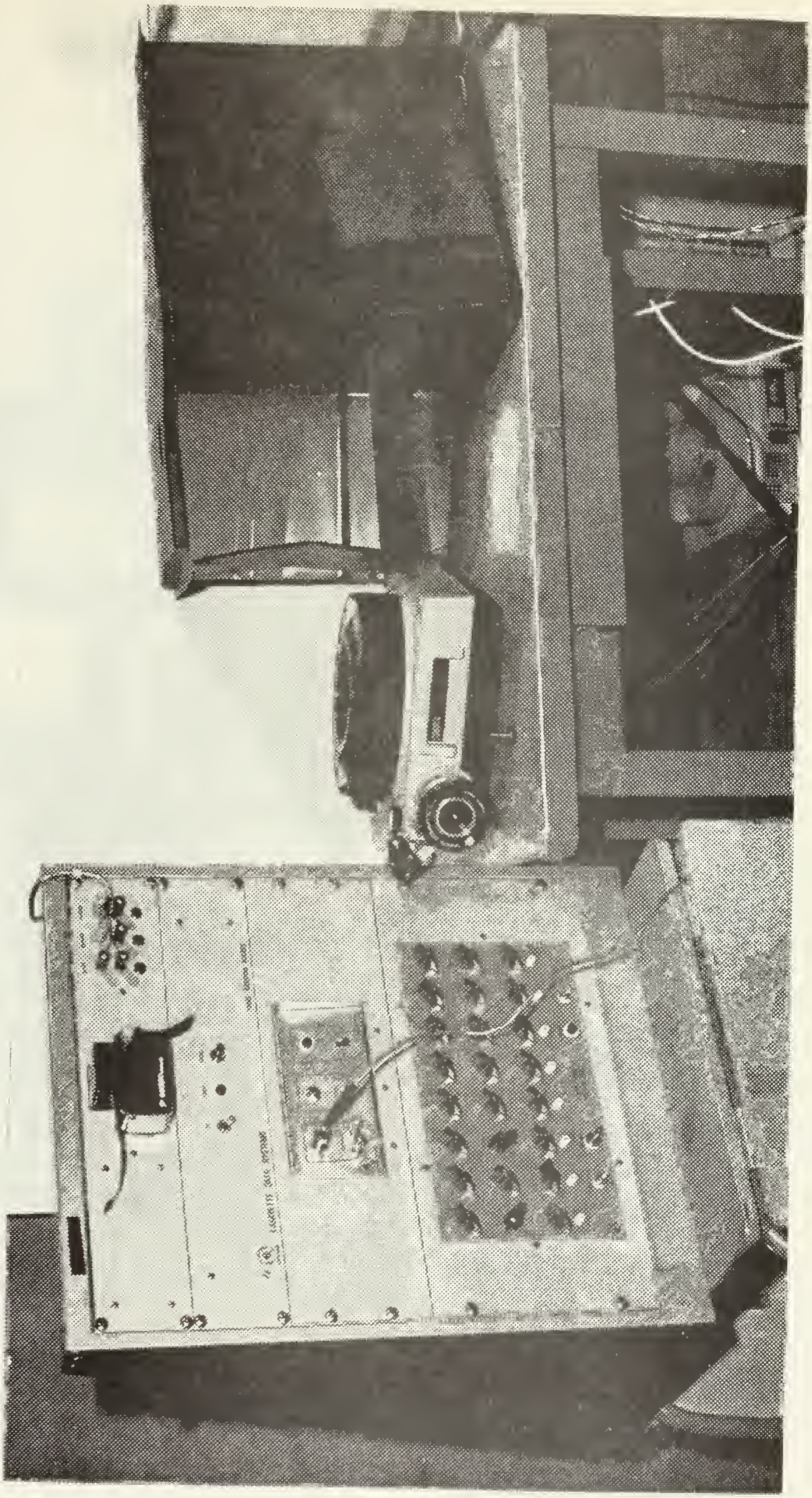
The use of the percentage change in minimum pupil diameter as a sensitive measure of subject responses to the treatments was also confirmed in this experiment. Further evaluation of the use of peak and button-press latency times and subject blink rates as measures of problem difficulty in future pupillary research is strongly suggested.

APPENDIX A

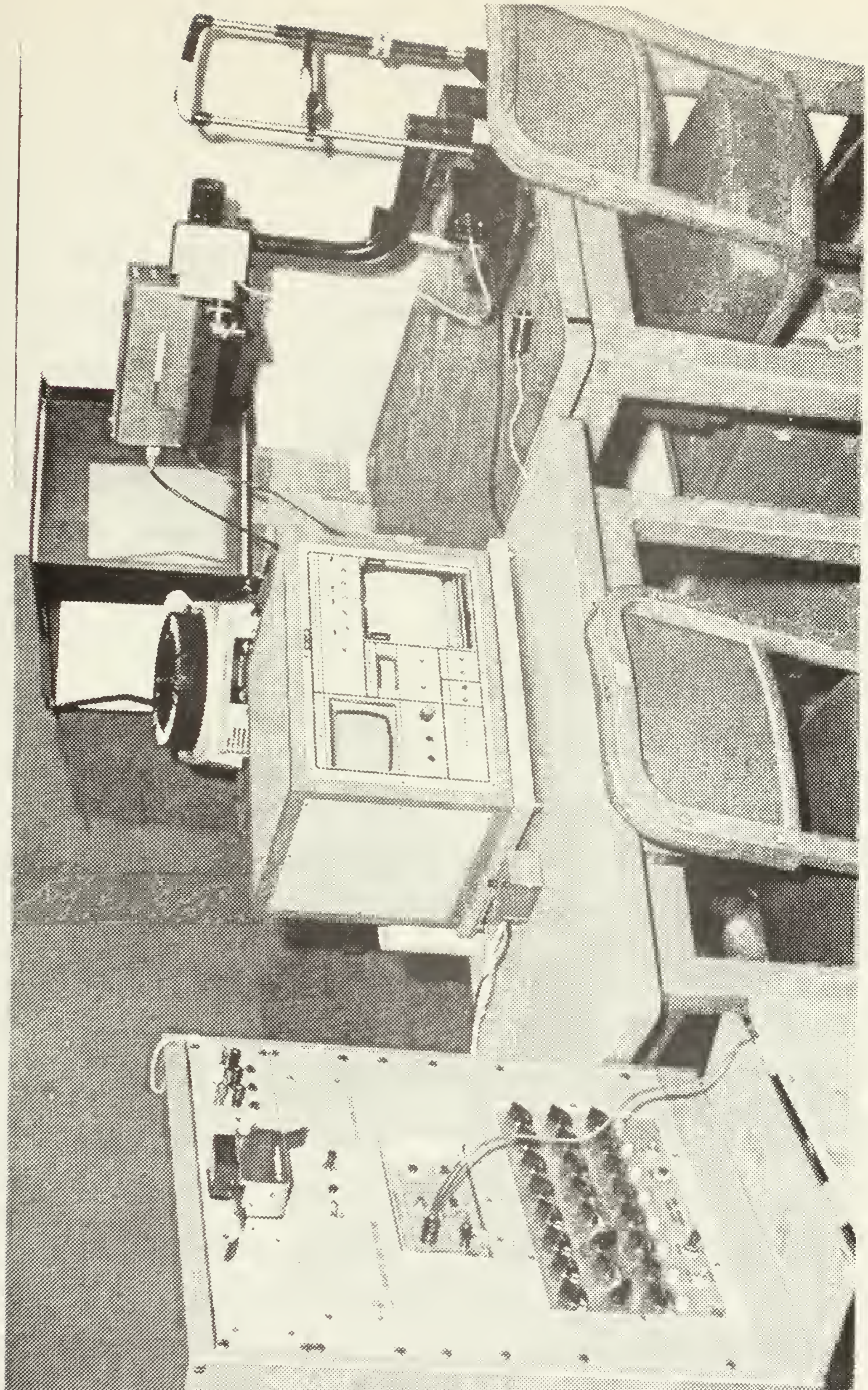
APPARATUS



The Space Sciences Incorporated Model 830 TV Pupillometer



The Lafayette Instrument Company Random Access Projection Tachistoscope System



Arrangement of TV Pupillometer and Random Access Projection Tachistoscope System as used during the experiment.

APPENDIX B

EXPERIMENTER'S INSTRUCTIONS

1. This is an experiment designed to measure eye responses to various stimuli. You are informed of this fact so that you will not try to outguess or anticipate the experimenter as you undergo the experimental tasks.
2. You may have your own ideas about eye responses, especially with respect to yourself, but you are asked to forget all that you know or have heard about eye responses and follow the instructions given to you.
3. In the experiment you will be asked to place your chin on the chin rest in the head holder in front of you. Adjustments will then be made to make you as comfortable as possible and to focus the camera on your left eye. Once this is accomplished, you will be asked to limit head movement as much as possible until completion of the test. If at any time during the experiment you are highly uncomfortable or some other factor is preventing you from concentrating on the experiment, immediately inform me of this fact following the completion of the subtask you are undergoing.
4. You will first be given a few initial tasks to perform and then will perform in turn 3 major tasks each of which consists of 3 subtasks. A brief explanation will precede each major task and a trial run will be administered for those tasks which

are the most difficult to understand. At the beginning of each subtask, I will alert you by saying "Ready?". You will perform each subtask to the best of your ability and will give me your verbal responses ONLY WHEN I ASK FOR THEM!! Please do not vocalize your mental processes! You will be instructed to close your eyes between each subtask and will fixate your eyes on a designated slide between each major task.

5. When using the button-press, you are asked to completely depress the button as you view the appropriate object on the slide shown. If you realize that you made a mistake, forget it.
6. You are permitted to blink your eyes as you deem necessary.
7. Following the experiment you will be asked a few questions with regard to how the experiment affected you.
8. Please do not disclose the purpose of the test or its method to prospective subjects.
9. Thank you for your assistance!

DO YOU HAVE ANY QUESTIONS?

EXPERIMENTAL DATA SHEET

TIME: Began - ________ Ended - ________ Subject # ________

I. PERSONAL INFORMATION

Subject's Name - ____________________ Age - ________

Section - ____________ Duty - ____________________
(Aviator, Submariner, etc.)

Phone Number - ____________ Color Blind? YES NO (Circle)

Wear Glasses? YES NO (Circle) If YES, How often? ____________

Any history of head or eye injuries? YES NO (circle)

If YES, briefly explain extent of injury - ____________________

____

II. CONTROL TESTS

A. Visual Shifts (Control Slide #1)

Number Viewed (3 sec)	Baseline 5	1	2	3	4	5
Pupil Size (mm)						
% of Change	X					
No. of eye blinks						

SUBJECT CLOSES EYES!!

B. Light Reflexive Effects (Control Slide #2)

Color Viewed (3 sec)	WHITE (upper left)	BLACK (upper right)	WHITE (low right)	GREY (low left)	WHITE (upper left)
Pupil Size (mm)					
% of Change	X				
No. of eye blinks					

SUBJECT CLOSES EYES!!

C. Accomodative Effects (Control Slide #1)

(Point #1)
Distance of Screen from Subject - ________ cm

(Point #2)
Distance of other point from S - ________ cm

SUBJECT CONTINUES LOOKING AT "5" on CONTROL SLIDE #1!!

Point Viewed (5sec)	1	2	1
Pupil Size			
% of change	X		
No. of blinks			

APPENDIX C (Con't)

III. FIRST MAJOR TASK - A B C (Circle)

Pupil Baseline - ________mm Blink Baseline - ________blinks/sec.

EXPLAIN TASK & ADMINISTER TRIAL RUN!!

Subtask #	Total Problem Time (sec)	% of change at peak (mm)	Time to peak (sec)	% of dropoff from peak	Time to drop-off (sec)	Final % of change from Baseline	% of Error in Answer	Latency Times (sec)		No. of eye blinks	
								Pupil	Task		

SUBJECT LOOKS AT "5" ON CONTROL SLIDE #1 UNTIL NEXT TASK!!!

IV. SECOND MAJOR TASK - A B C (Circle)

Pupil Baseline - ________mm Blink Baseline - ________blinks/sec.

EXPLAIN TASK & ADMINISTER TRIAL RUN!!

Subtask #	Total Problem Time (sec)	% of change at peak	Time to peak (sec)	% of dropoff from peak	Time to drop-off (sec)	Final % of change from Baseline	% of Error in Answer	Latency Times (sec)		No. of eye blinks	
								Pupil	Task		

SUBJECT LOOKS AT "5" ON CONTROL SLIDE #1 UNTIL NEXT TASK!!!

V. THIRD MAJOR TASK - A B C (Circle)

Pupil Baseline - ________mm Blink Baseline - ________blinks/sec.

EXPLAIN TASK & ADMINISTER TRIAL RUN!!

Subtask #	Total Problem Time (sec)	% of change at peak	Time to peak (sec)	% of dropoff from peak	Time to drop-off (sec)	Final % of change from Baseline	% of Error in Response	Latency Times (sec)		No. of blinks
								Pupil	Task	

REMOVE SUBJECT FROM MACHINE - TESTING IS COMPLETED!!!

VI. FINAL COMMENTS

A. Did Subject notice any blurring of his vision during any subtasks?

YES NO (Circle)

If YES - (1) Which subtask(s)? ____________________

(2) When did blurring occur? ____________________

(3) Extent of blurring? ____________________

(4) How long did blurring last? ____________________

B. Did Subject experience any difficulty with the subtasks? YES NO (Circle)

If YES - (1) Which subtask(s)? ____________________

(2) Nature of difficulty? ____________________

____

(3) Reason for difficulty? ____________________

____

C. Subject's critique of experiment - ____________________

____

____

____

____

____

____

EXPERIMENTAL DATA SHEET

TIME: Began - ________ Ended - ________ Subject # ______

I. PERSONAL INFORMATION

Subject's Name - ______________________________ Age - ______

Section - ______________ Duty - ____________________
(Aviator, Submariner, etc.)

Phone Number - ______________ Color Blind? YES NO (Circle)

Wear Glasses? YES NO (Circle) If YES, How often? ____________

Any history of head or eye injuries? YES NO (circle)

If YES, briefly explain extent of injury - ______________________

____

II. CONTROL TESTS

A. Visual Shifts (Control Slide #1)

Number Viewed (3 sec)	Baseline 5	1	2	3	4	5
Pupil Size (mm)						
% of Change	X					
No. of eye blinks						

SUBJECT CLOSES EYES!!

B. Light Reflexive Effects (Control Slide #2)

Color Viewed (3 sec)	WHITE (upper left)	BLACK (upper right)	WHITE (low right)	GREY (low left)	WHITE (upper left)
Pupil Size (mm)					
% of Change	X				
No. of eye blinks					

SUBJECT CLOSES EYES!!

C. Accomodative Effects (Control Slide #1)

(Point #1)
Distance of Screen from Subject - ________ cm

(Point #2)
Distance of other point from S - ________ cm

SUBJECT CONTINUES LOOKING AT "5" on CONTROL SLIDE #1!!

Point Viewed (5sec)	1	2	1
Pupil Size			
% of change	X		
No. of blinks			

III. FIRST MAJOR TASK - A B C (Circle)

Pupil Baseline - __________mm Blink Baseline - __________blinks/sec.

EXPLAIN TASK & ADMINISTER TRIAL RUN!!

btask #	Total Problem Time (sec)	% of change at peak (mm)	Time to peak (sec)	% of dropoff from peak	Time to drop-off (sec)	Final % of change from Baseline	% of Error in Answer	Latency Times (sec)		No. of eye blinks	
								Pupil	Task		

SUBJECT LOOKS AT "5" ON CONTROL SLIDE #1 UNTIL NEXT TASK!!!

IV. SECOND MAJOR TASK - A B C (Circle)

Pupil Baseline - __________mm Blink Baseline - __________blinks/sec.

EXPLAIN TASK & ADMINISTER TRIAL RUN!!

task	Total Problem Time (sec)	% of change at peak	Time to peak (sec)	% of dropoff from peak	Time to drop-off (sec)	Final % of change from Baseline	% of Error in Answer	Latency Times (sec)		No. of eye blinks	
								Pupil	Task		

SUBJECT LOOKS AT "5" ON CONTROL SLIDE #1 UNTIL NEXT TASK!!!

V. THIRD MAJOR TASK - A B C (Circle)

Pupil Baseline - __________mm Blink Baseline - __________blinks/sec.

EXPLAIN TASK & ADMINISTER TRIAL RUN!!

Subtask #	Total Problem Time (sec)	% of change at peak	Time to peak (sec)	% of dropoff from peak	Time to drop-off (sec)	Final % of change from Baseline	% of Error in Response	Latency Times (sec)		No. of blinks	
								Pupil	Task		

REMOVE SUBJECT FROM MACHINE - TESTING IS COMPLETED!!!

VI. FINAL COMMENTS

A. Did Subject notice any blurring of his vision during any subtasks?

YES NO (Circle)

If YES - (1) Which subtask(s)? ____________________

(2) When did blurring occur? ____________________

(3) Extent of blurring? ____________________

(4) How long did blurring last? ____________________

B. Did Subject experience any difficulty with the subtasks? YES NO (Circle

If YES - (1) Which subtask(s)? ____________________

(2) Nature of difficulty? ____________________

____

(3) Reason for difficulty? ____________________

____

C. Subject's critique of experiment - ____________________

____

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____

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____

APPENDIX D

STIMULI PRESENTATION ORDER

I. Description of Tasks and Subtasks.

TASK	TASK DESCRIPTION
A	Visual mental stimulus - Subject performs mental mathematical operations as indicated by slides.
B	Visual arousal stimulus - Subject views slides of semi-nude and nude women.
C	Visual perceptual motor stimulus - Subject views slides containing symbols and counts only dots by means of button-press.

SUBTASK	SUBTASK DESCRIPTION
1	Easy subtask - Subject should have little difficulty in accurately completing the subtask.
2	Moderate subtask - Subject should experience some difficulty in accurately completing the subtask.
3	Difficult subtask - Subject should experience the most difficulty (when compared with the Easy and Moderate Subtasks) in accurately completing the subtask.

II. Assignment of treatments among subjects:

(The parentheses indicate which subject, by number, was assigned to the specific treatment listed below the number)

(1)	(2) & (19)	(3) & (20)	(4) & (21)	(5) & (22)	(6) & (23)
A 1 2 3	B 2 1 3	B 3 2 1	A 1 3 2	C 2 3 1	C 3 1 2
B 2 3 1	A 3 2 1	C 1 3 2	C 2 1 3	A 3 1 2	B 1 2 3
C 3 2 1	C 1 2 3	A 2 1 3	B 3 1 2	B 1 3 2	A 2 3 1

(7) & (24)	(8) & (25)	(9)	(10)	(11)	(12)
B 2 3 1	C 1 2 3	A 3 2 1	B 1 2 3	A 1 3 2	C 3 2 1
A 1 2 3	B 3 2 1	C 2 3 1	C 2 1 3	B 2 1 3	A 2 3 1
C 1 3 2	A 2 1 3	B 1 3 2	A 3 1 2	C 3 1 2	B 3 1 2

(13)	(14)	(15)	(16)	(17)	(18)
C 3 2 1	B 2 1 3	C 2 1 3	A 1 2 3	B 3 1 2	A 3 2 1
B 2 3 1	C 1 3 2	A 3 1 2	C 3 1 2	A 2 1 3	B 1 2 3
A 1 2 3	A 2 3 1	B 3 2 1	B 1 3 2	C 1 2 3	C 2 3 1

APPENDIX E

STIMULI USED IN EXPERIMENT

I. The slide stimuli used in this experiment are contained in this appendix and are arranged in the following order:

a. Ten trial problem slides of mental mathematics task.

b. Ten problem slides of easy subtask of mental mathematics task.

c. Ten problem slides of moderate subtask of mental mathematics task.

d. Ten problem slides of difficult subtask of mental mathematics task.

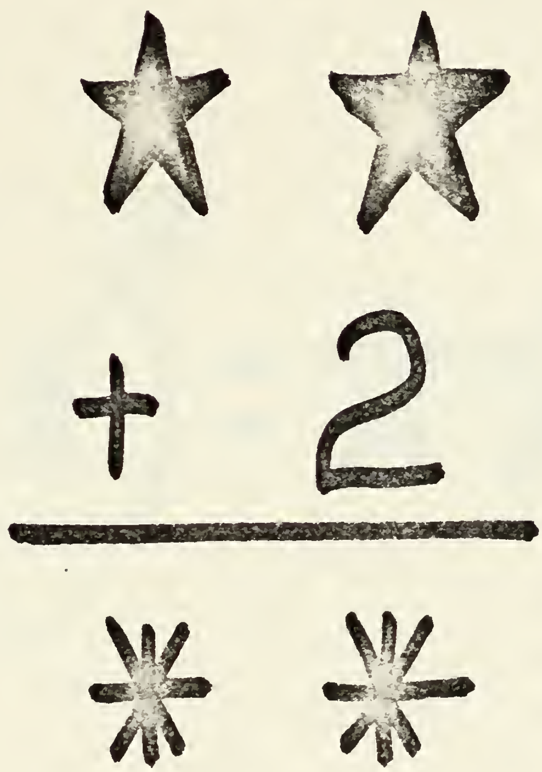
e. Ten problem slides of easy subtask of perceptual motor task.

f. Ten problem slides of moderate subtask of perceptual motor task.

g. Ten problem slides of difficult subtask of perceptual motor task.

Slide #1 - Trial - Mathematics Task

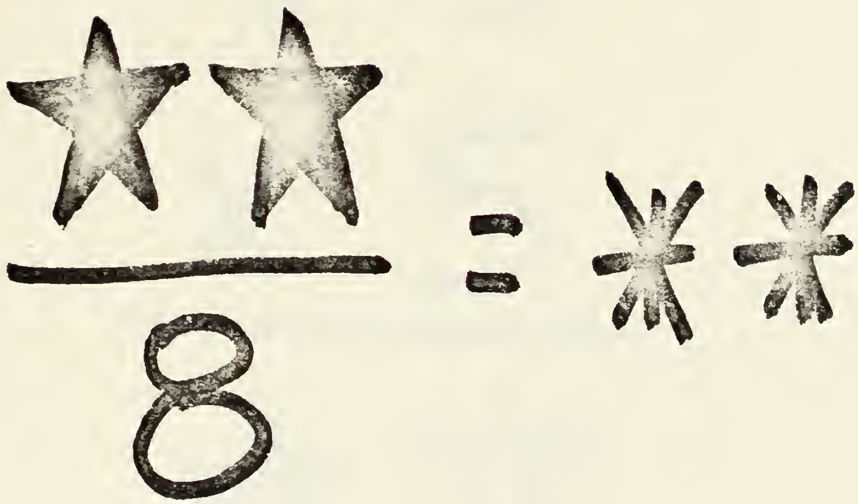
Slide #2 - Trial - Mathematics Task



Slide #3 - Trial - Mathematics Task

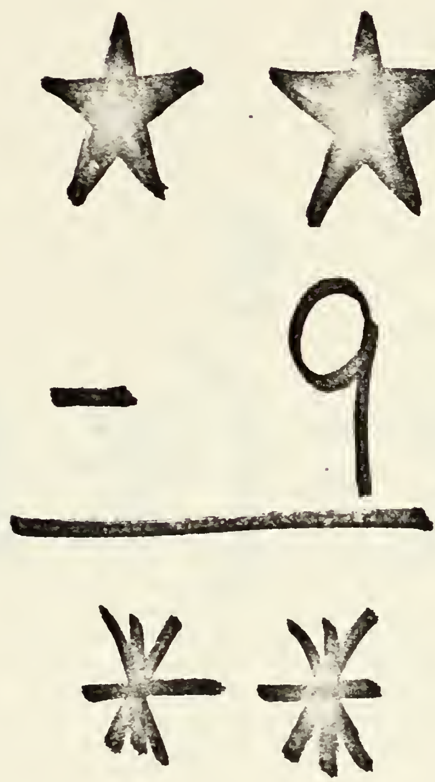
$$(\ast\ast)^2 = \star\star$$

Slide #4 - Trial - Mathematics Task



Slide #5 - Trial - Mathematics Task

Slide #6 - Trial - Mathematics Task

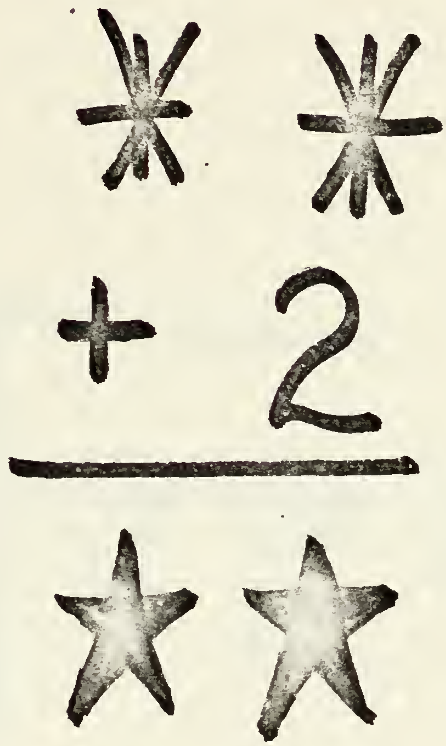


Slide #7 - Trial - Mathematics Task

$$(\ast\ast)^3 = \bigstar\bigstar$$

Slide #8 - Trial - Mathematics Task

Slide #9 - Trial - Mathematics Task

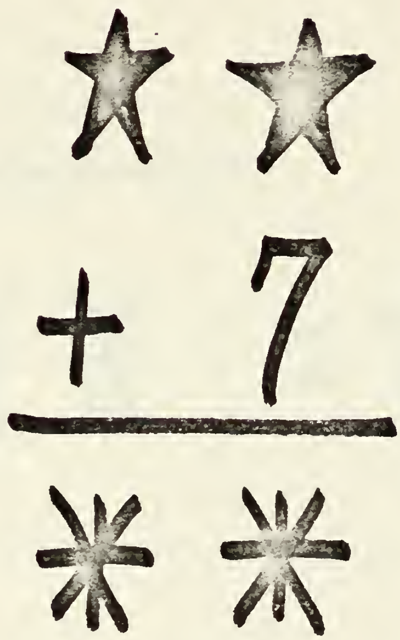


Slide #10 - Trial - Mathematics Task

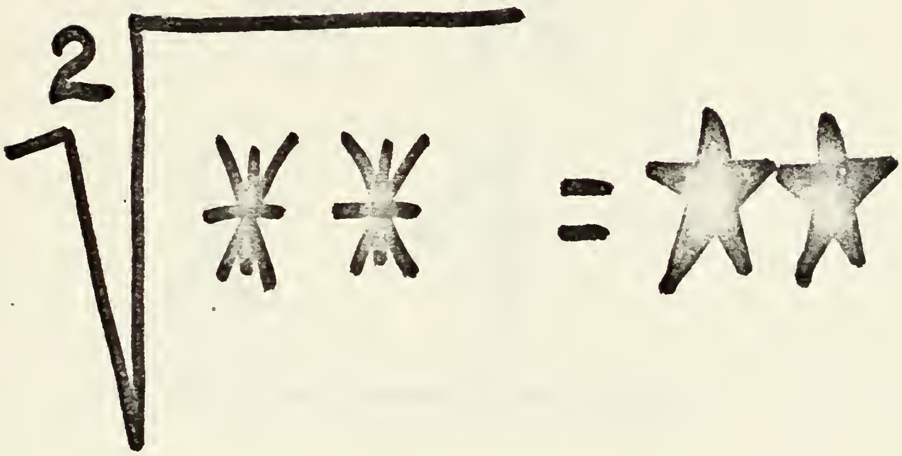
Slide #1 - Easy Subtask - Mathematics Task

$$\frac{10}{5} = \star\star$$

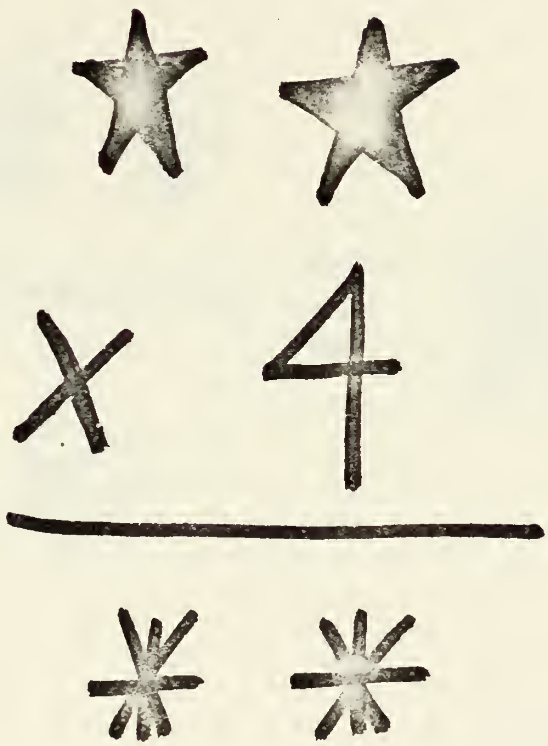
Slide #2 - Easy Subtask - Mathematics Task



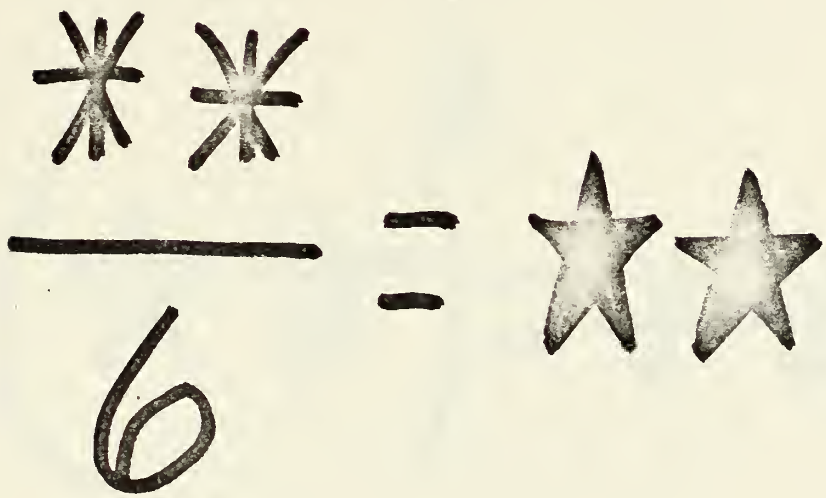
Slide #3 - Easy Subtask - Mathematics Task



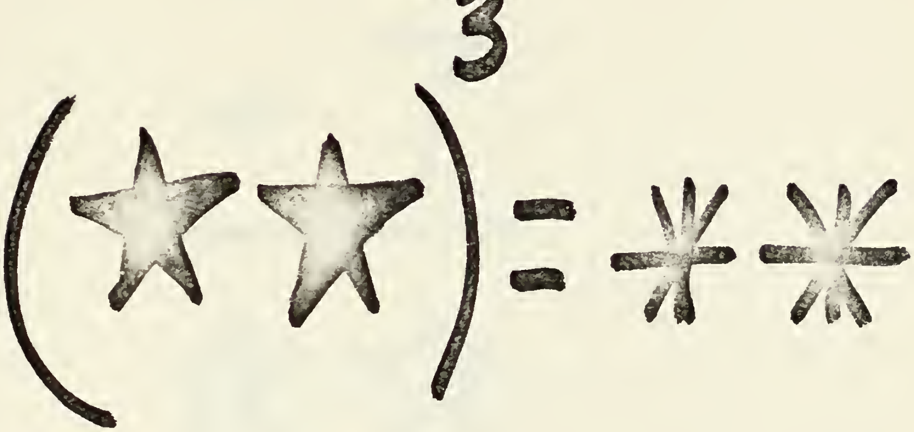
Slide #4 - Easy Subtask - Mathematics Task



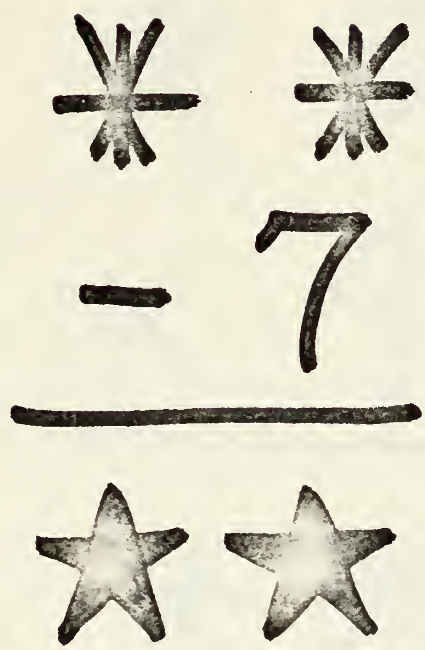
Slide #5 - Easy Subtask - Mathematics Task



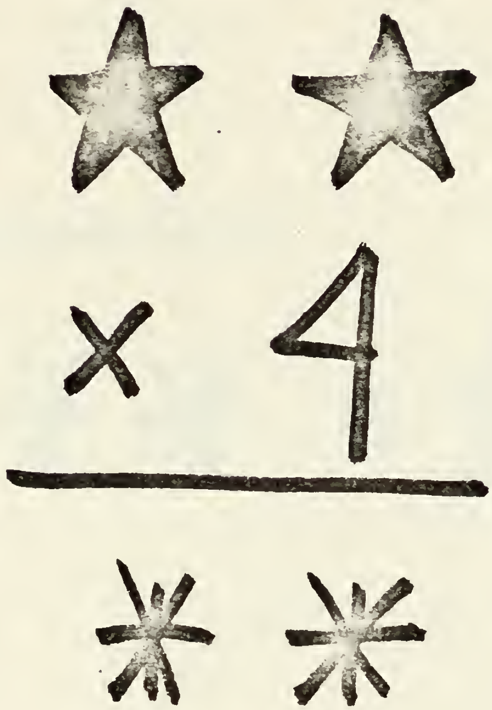
Slide #6 - Easy Subtask - Mathematics Task



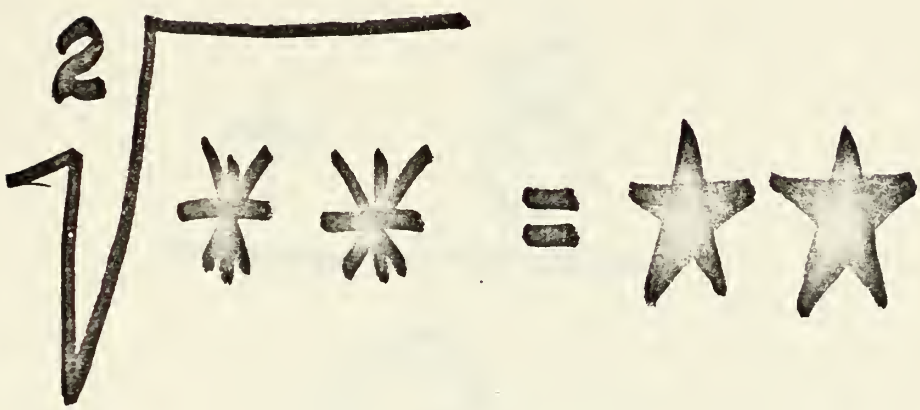
Slide #7 - Easy Subtask - Mathematics Task



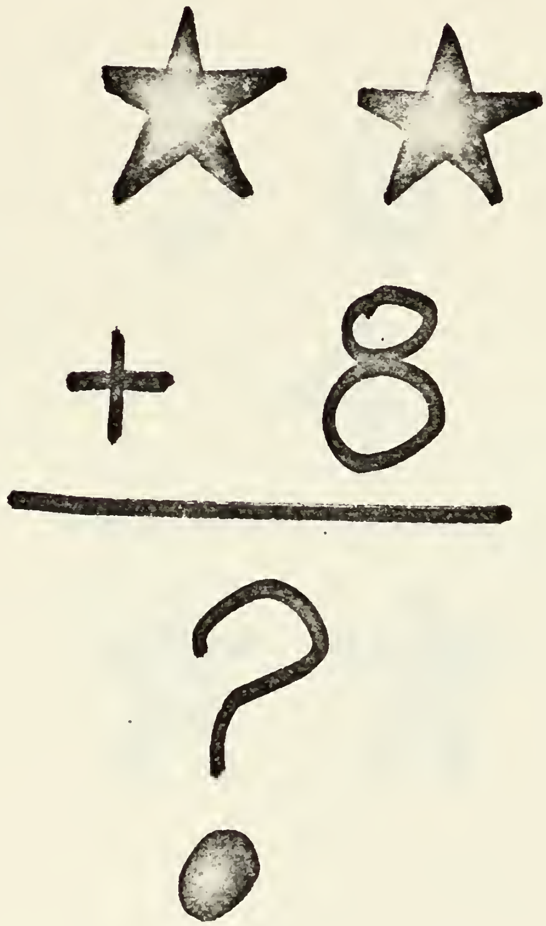
Slide #8 - Easy Subtask - Mathematics Task



Slide #9 - Easy Subtask - Mathematics Task



Slide #10 - Easy Subtask - Mathematics Task

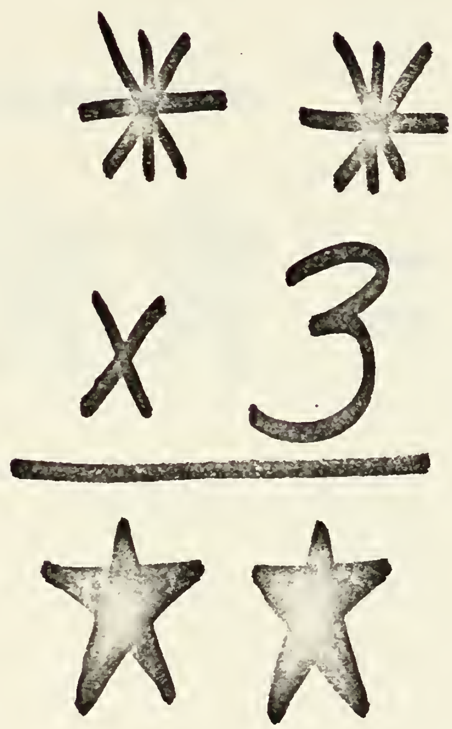


Slide #1 - Moderate Subtask - Mathematics Task

$$\begin{array}{r} 56 \\ +\ 4 \\ \hline \star\ \star \end{array}$$

Slide #2 - Moderate Subtask - Mathematics Task

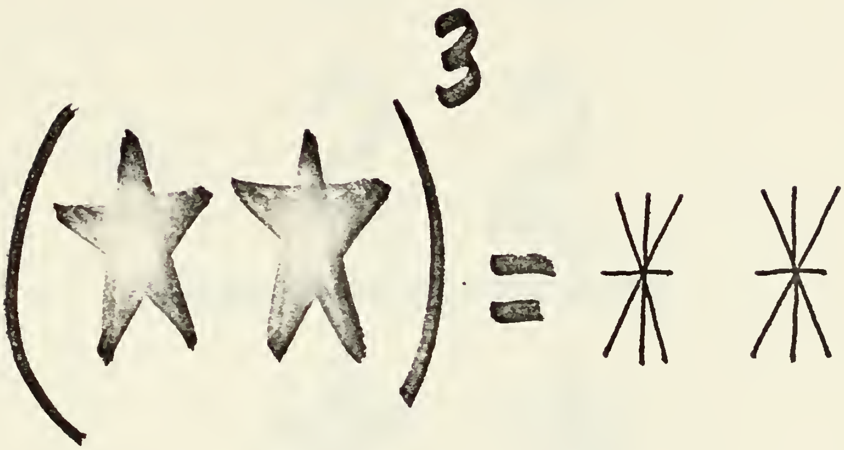
Slide #3 - Moderate Subtask - Mathematics Task



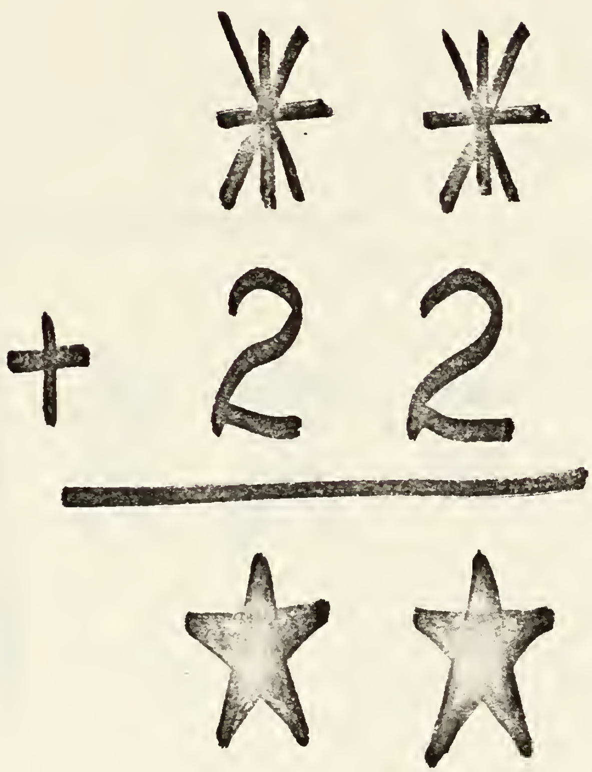
Slide #4 - Moderate Subtask - Mathematics Task

Slide #5 - Moderate Subtask - Mathematics Task

Slide #6 - Moderate Subtask - Mathematics Task

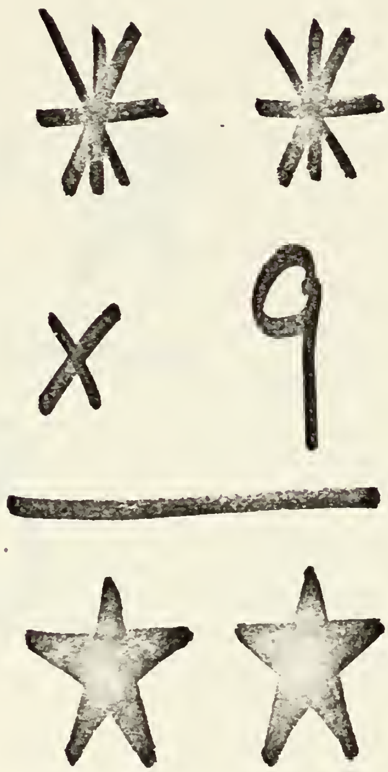


Slide #7 - Moderate Subtask - Mathematics Task

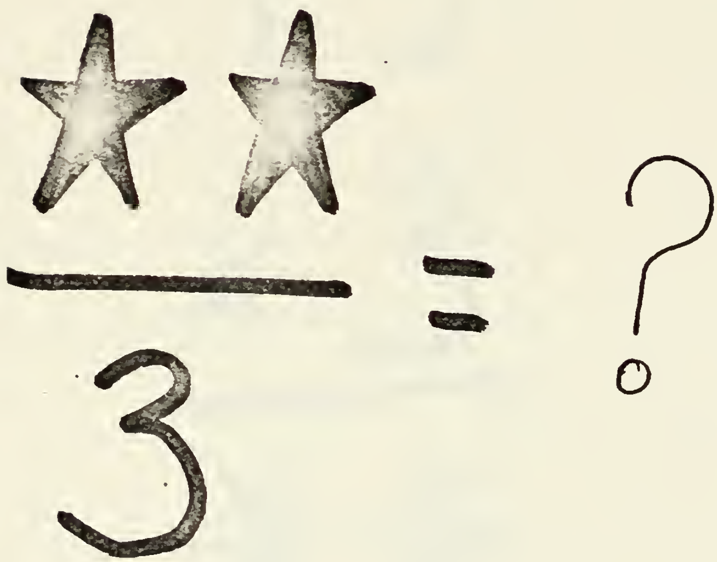


Slide #8 - Moderate Subtask - Mathematics Task

Slide #9 - Moderate Subtask - Mathematics Task



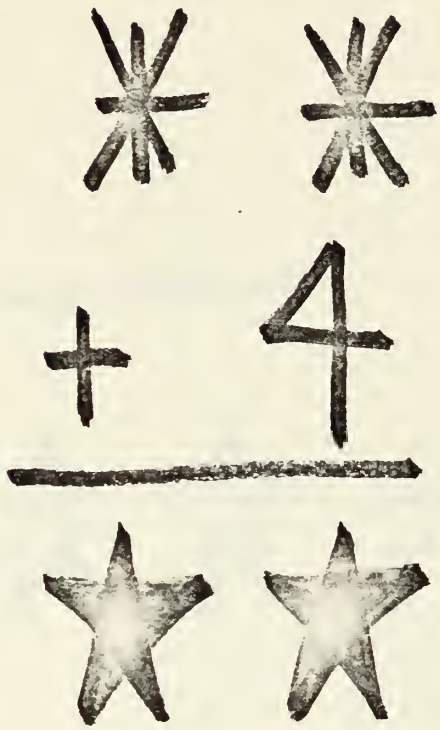
Slide #10 - Moderate Subtask - Mathematics Task



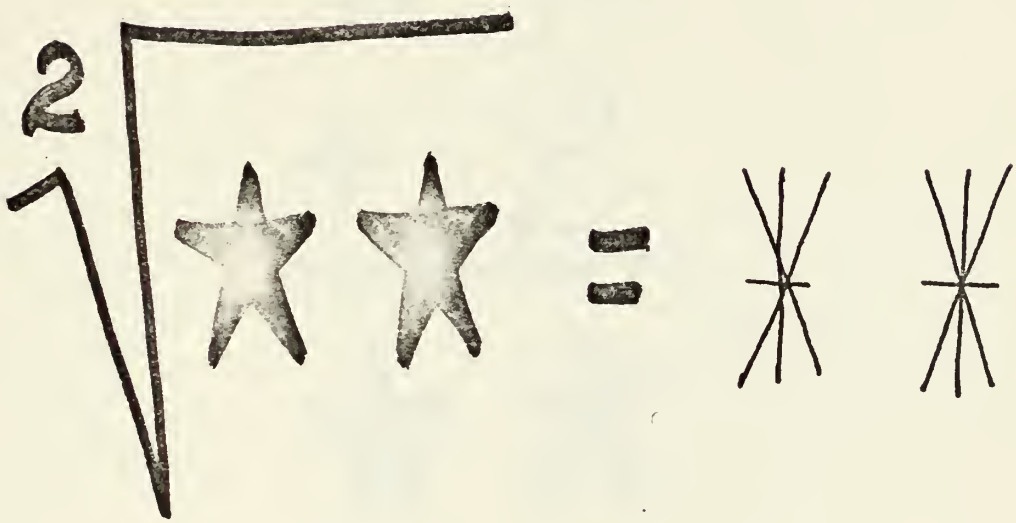
Slide #1 - Difficult Subtask - Mathematics Task

$$\begin{array}{r} 15 \\ \times\ 3 \\ \hline \ast\ast \end{array}$$

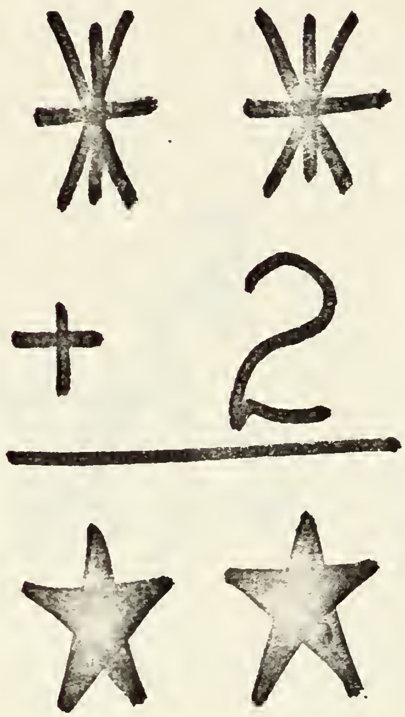
Slide #2 - Difficult Subtask - Mathematics Task



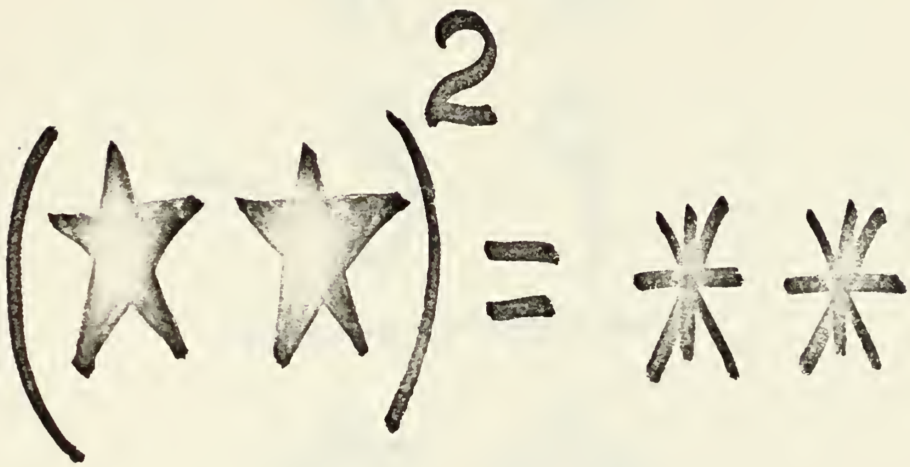
Slide #3 - Difficult Subtask - Mathematics Task



Slide #4 - Difficult Subtask - Mathematics Task



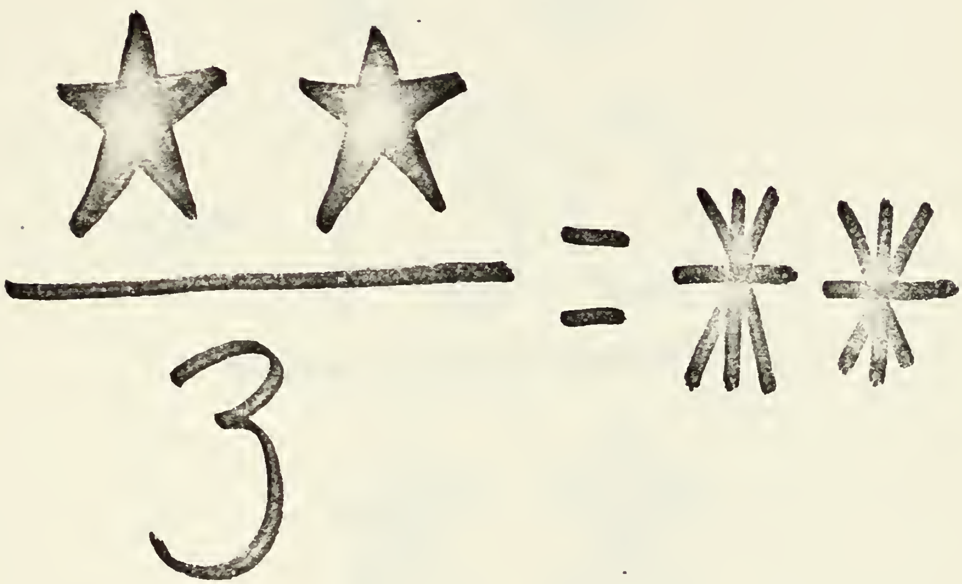
Slide #5 - Difficult Subtask - Mathematics Task



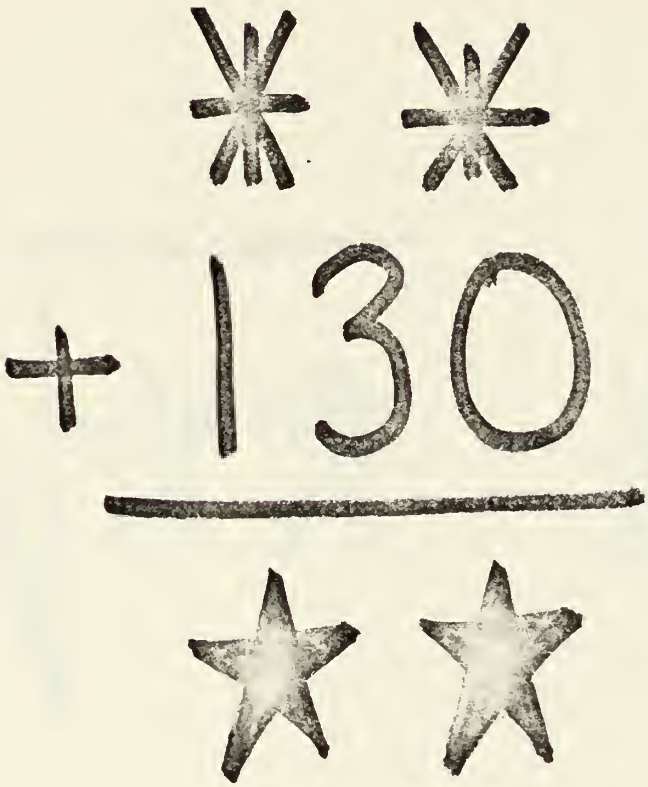
Slide #6 - Difficult Subtask - Mathematics Task

$$\begin{array}{r} \ast\ \ast \\ -\,3\ 9 \\ \hline \star\ \star \end{array}$$

Slide #7 - Difficult Subtask - Mathematics Task



Slide #8 - Difficult Subtask - Mathematics Task

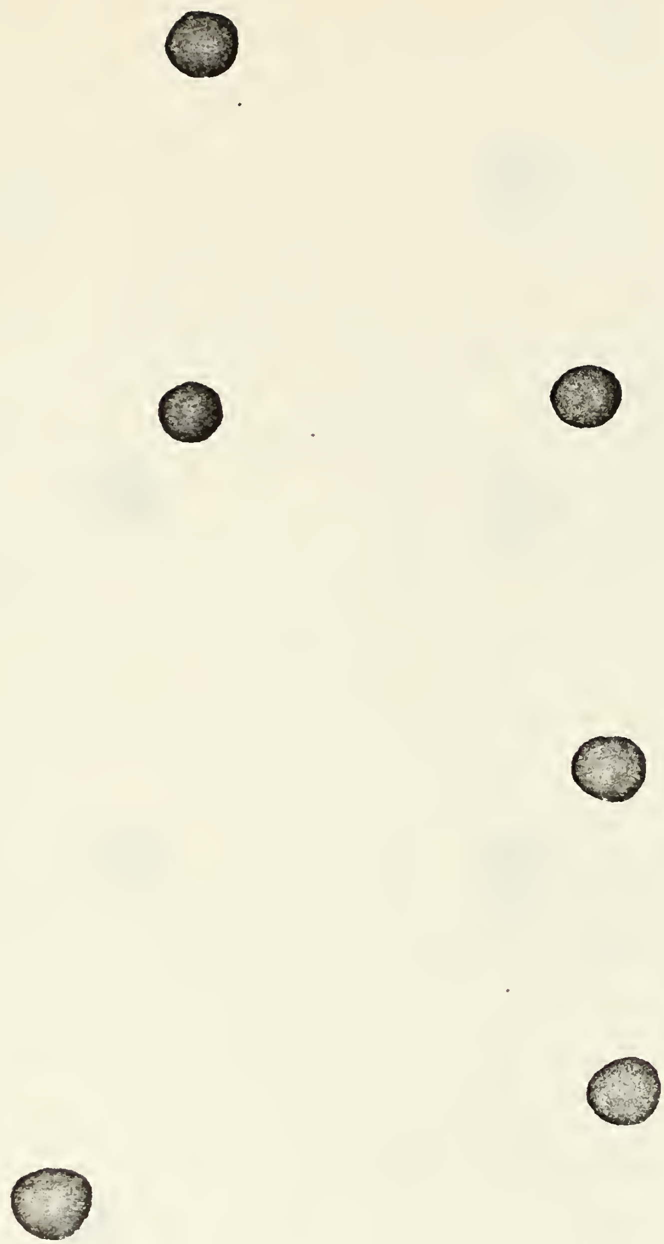


Slide #9 - Difficult Subtask - Mathematics Task

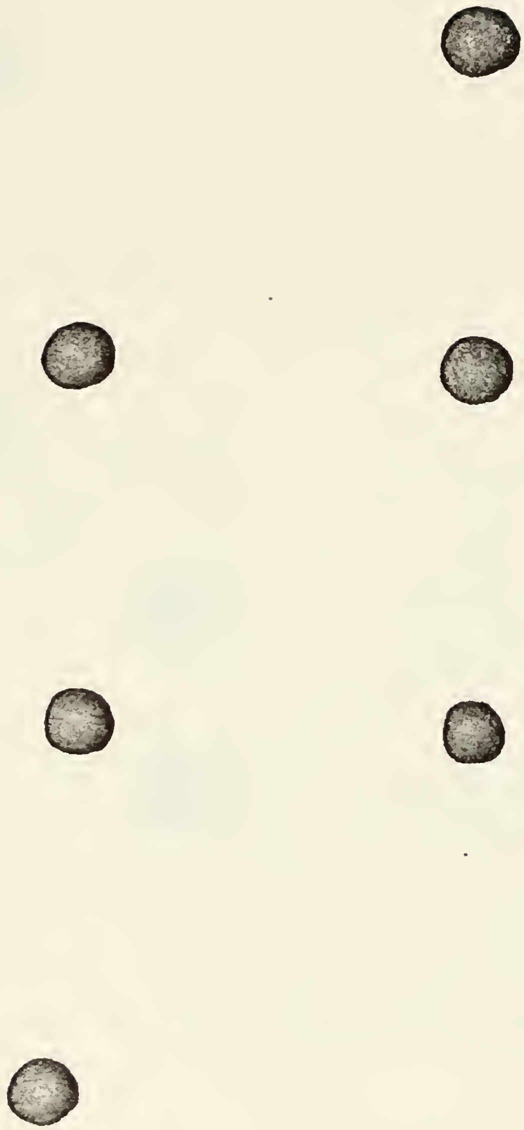
Slide #10 - Difficult Subtask - Mathematics Task

$$\begin{array}{r} * \ * \\ \times \ \ 9 \\ \hline ? \end{array}$$

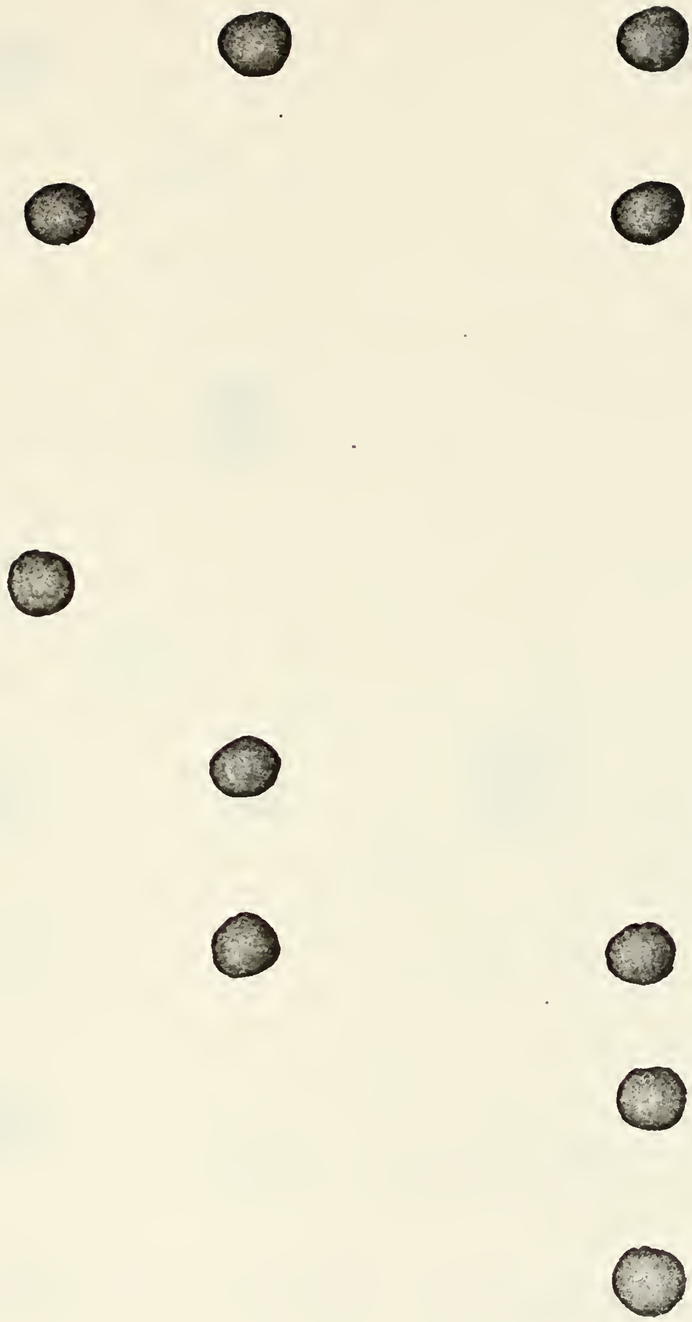
Slide #1 - Easy Subtask - Perceptual Motor Task



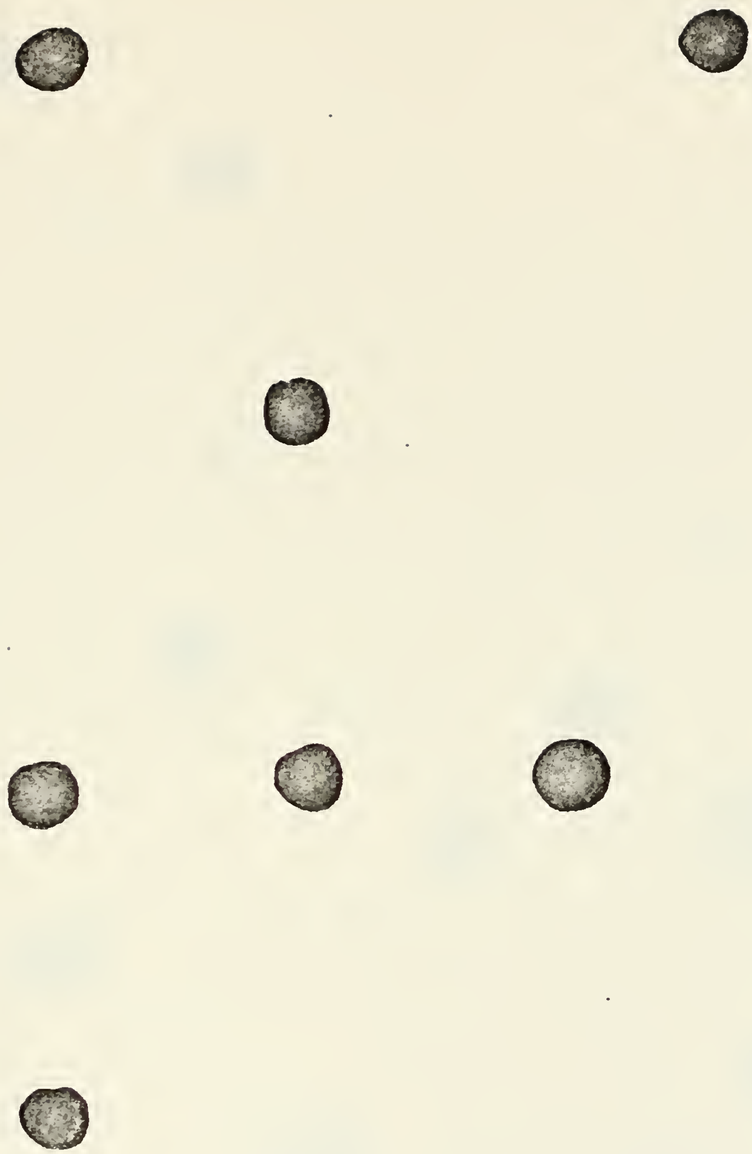
Slide #2 - Easy Subtask - Perceptual Motor Task



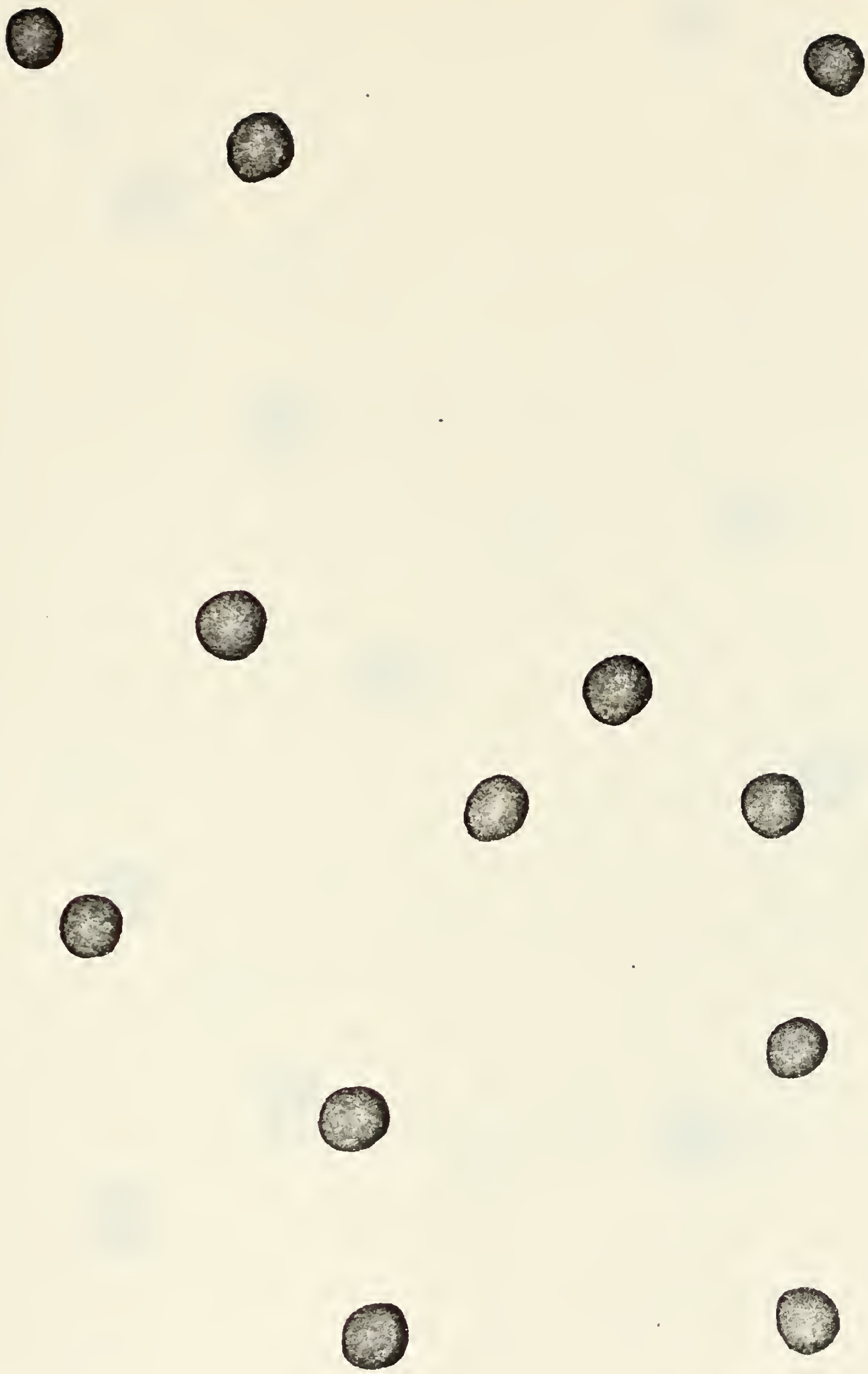
Slide #3 - Easy Subtask - Perceptual Motor Task



Slide #4 - Easy Subtask - Perceptual Motor Task

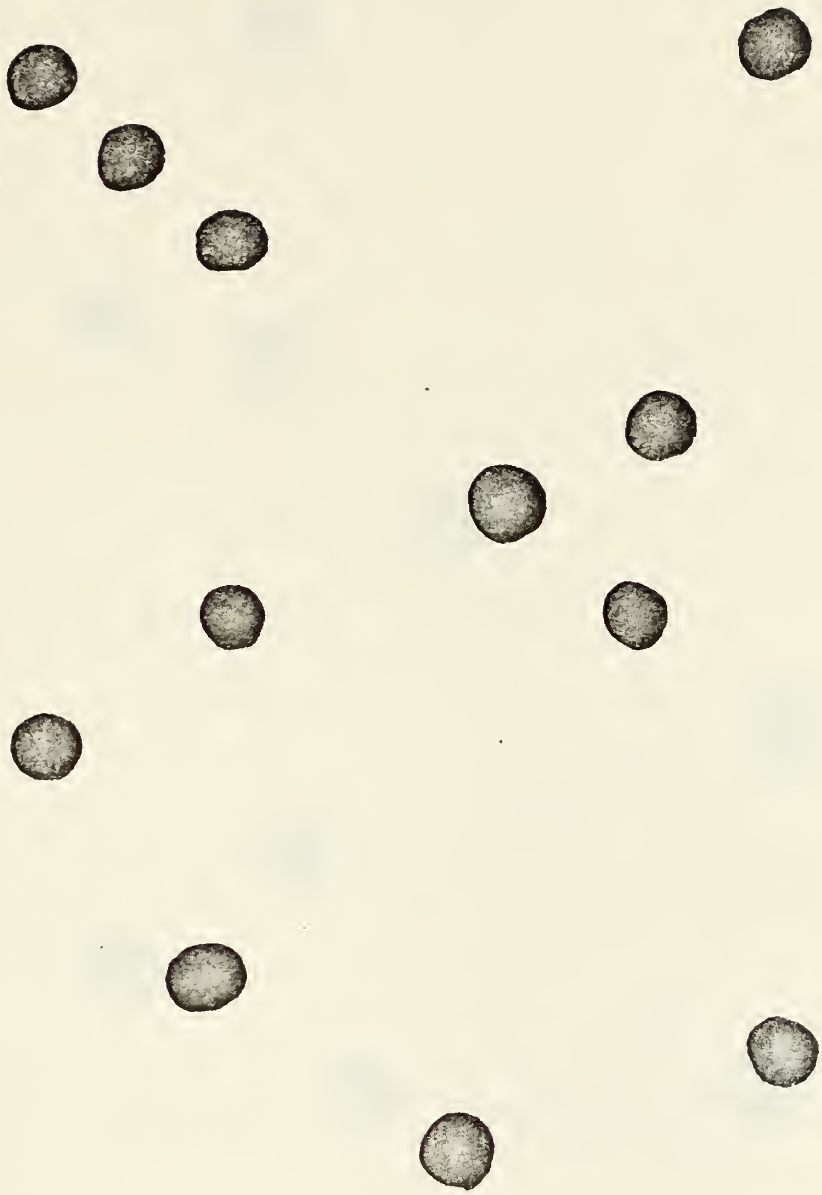


Slide #5 - Easy Subtask - Perceptual Motor Task

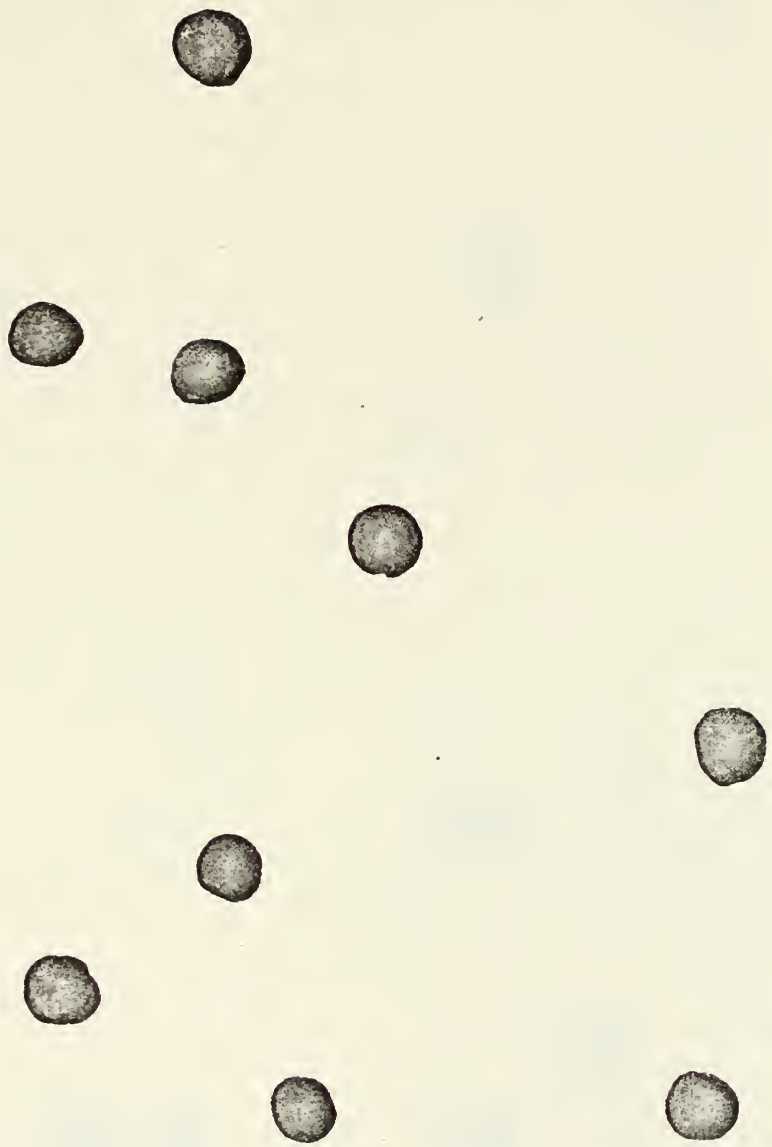


Slide #6 - Easy Subtask - Perceptual Motor Task

Slide #7 - Easy Subtask - Perceptual Motor Task

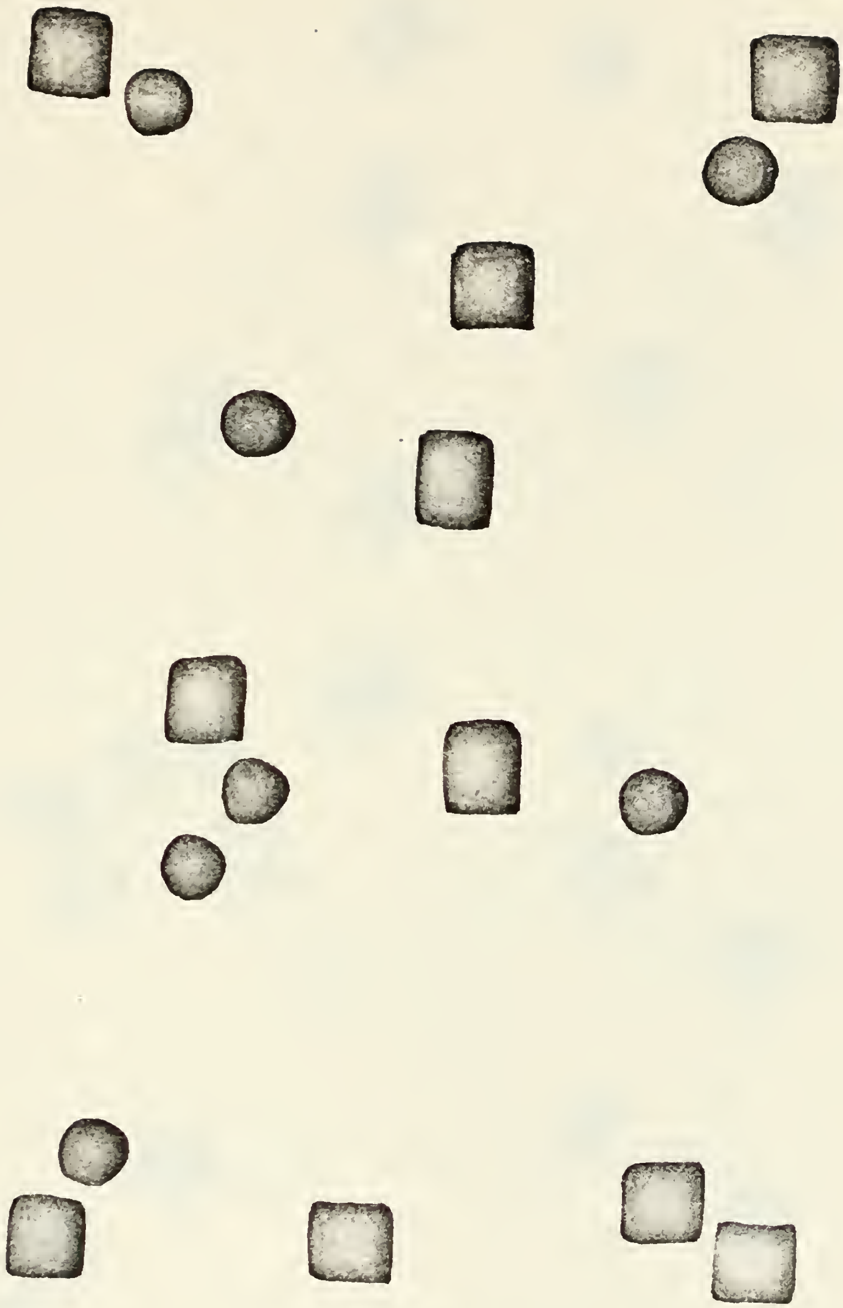


Slide #8 - Easy Subtask - Perceptual Motor Task

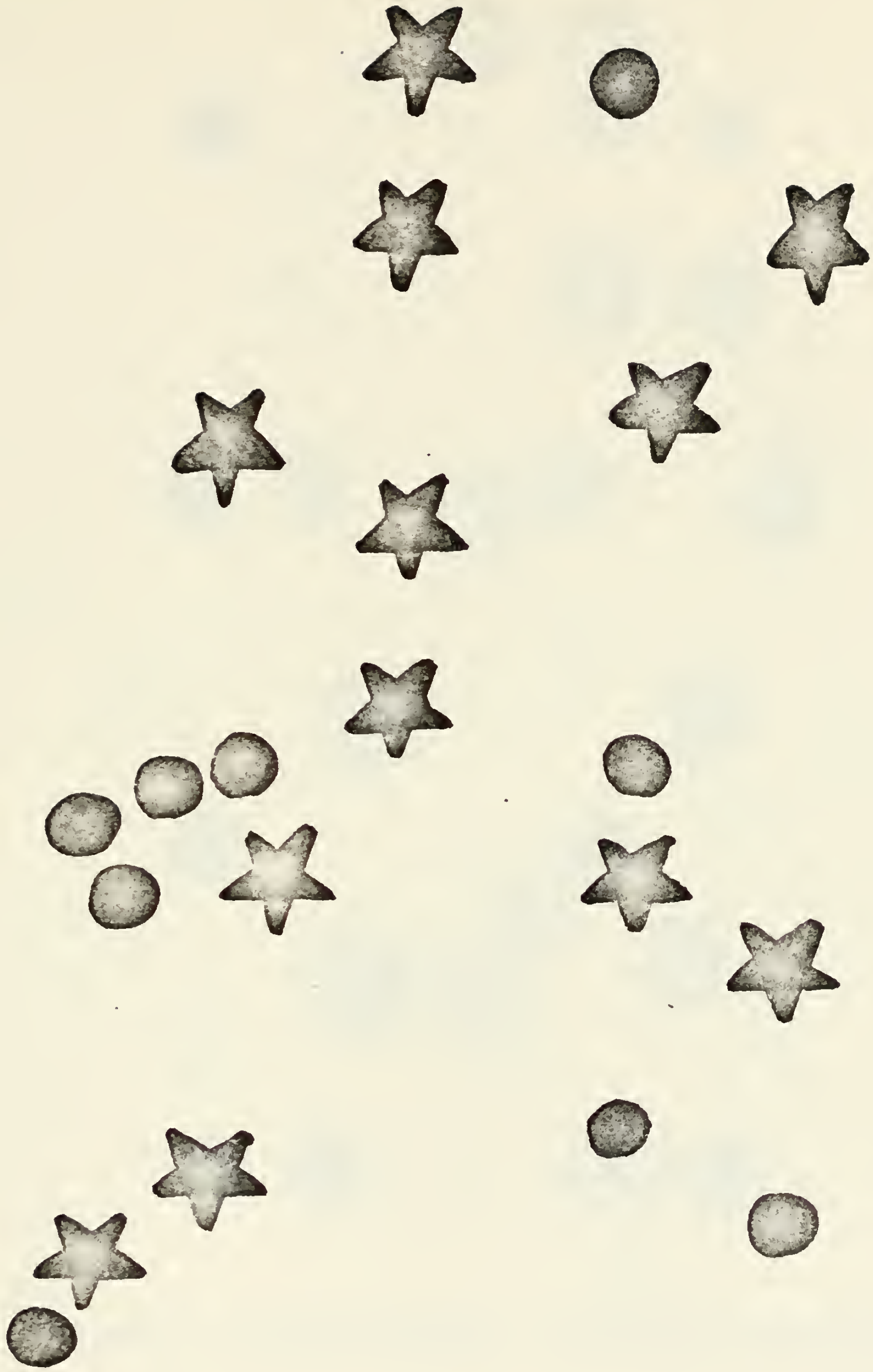


Slide #9 - Easy Subtask - Perceptual Motor Task

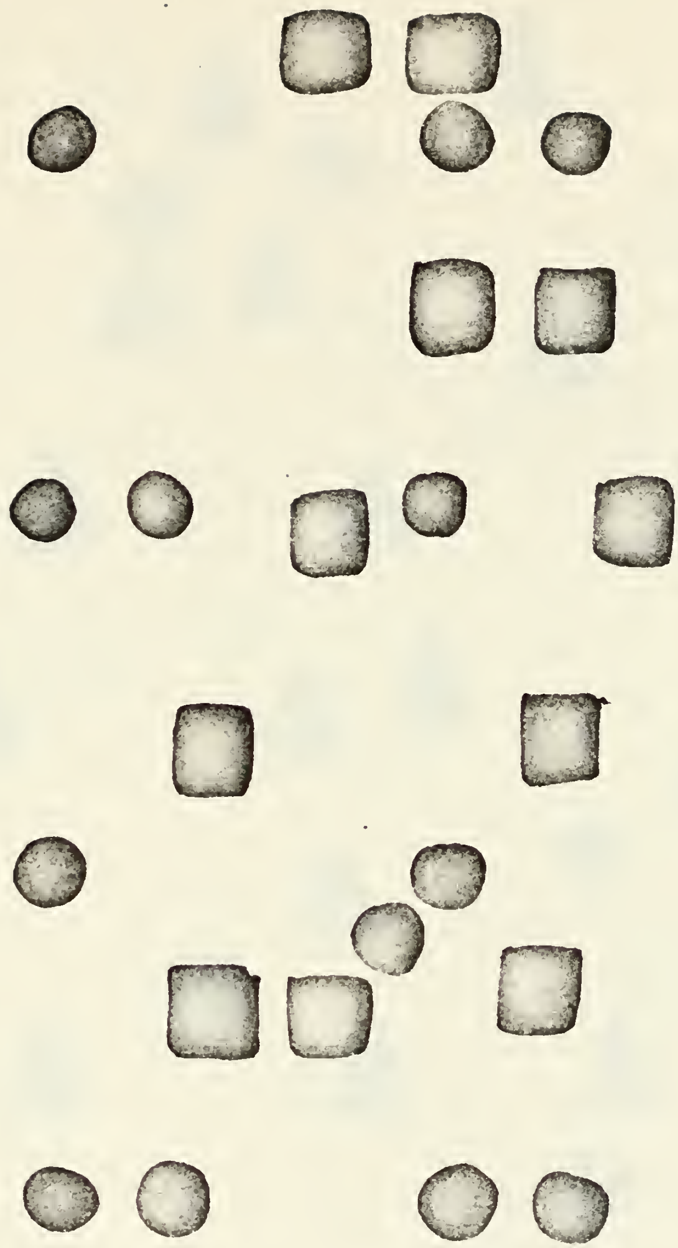
Slide #10 - Easy Subtask - Perceptual Motor Task



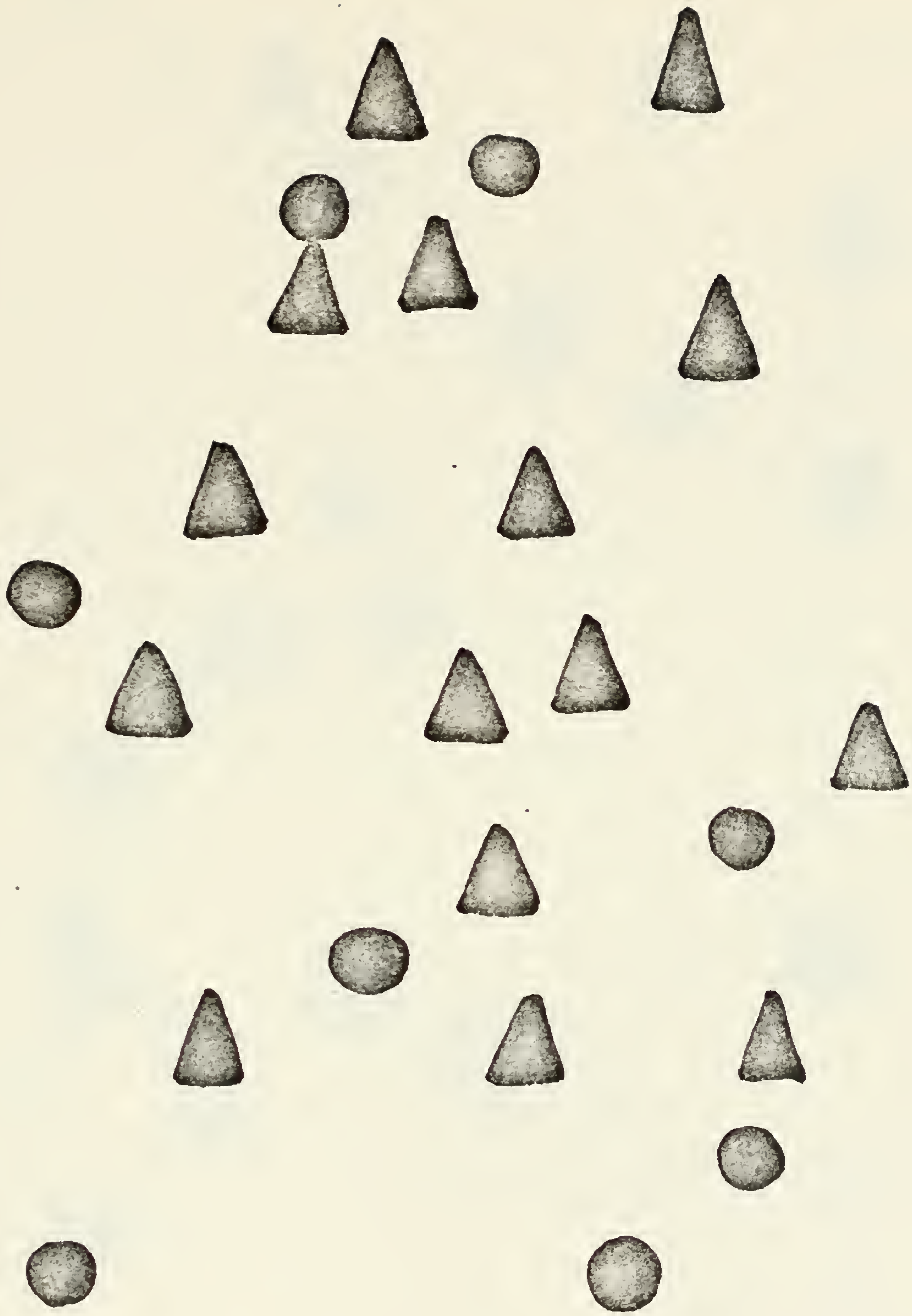
Slide #1 - Moderate Subtask - Perceptual Motor Task



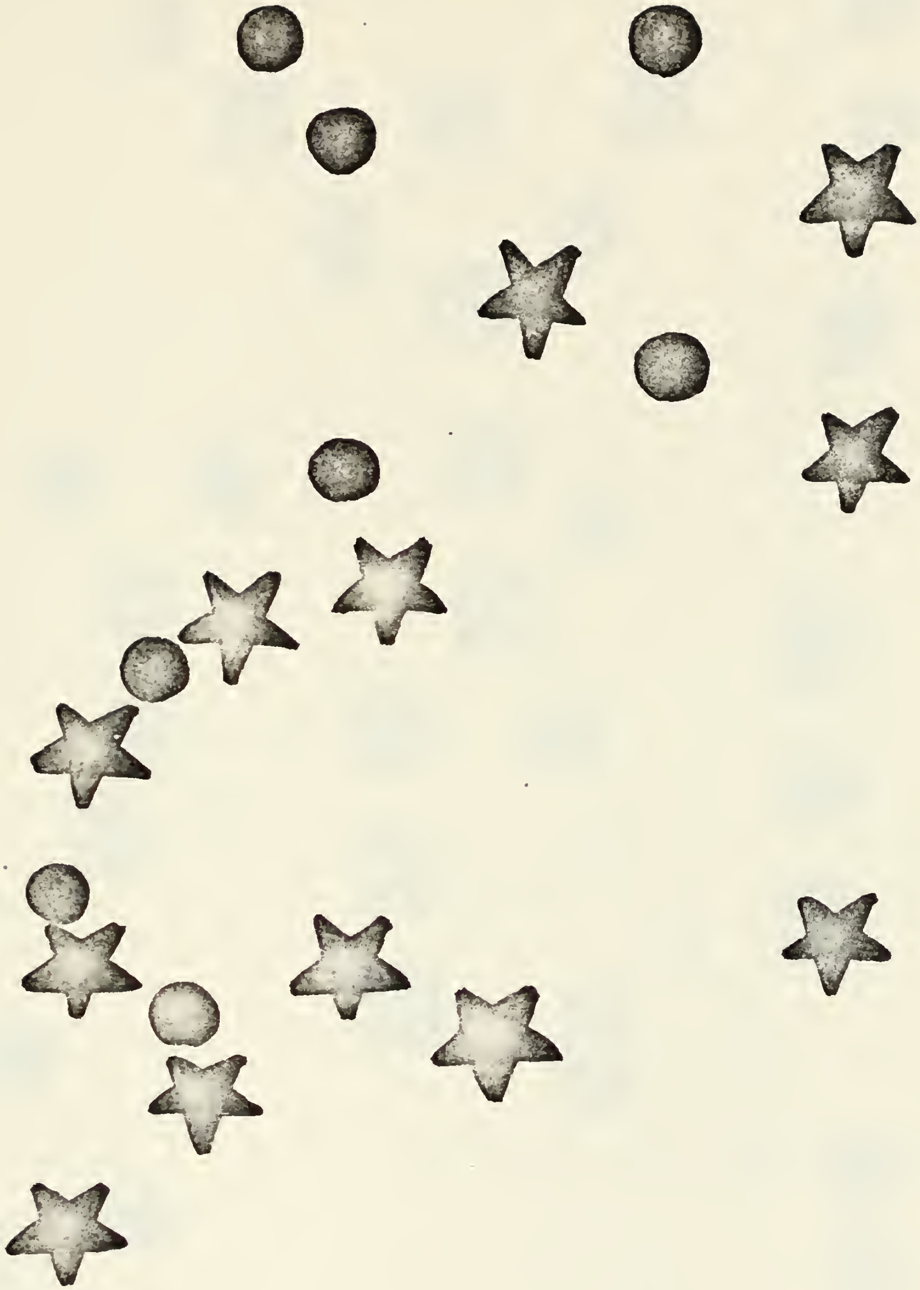
Slide #2 - Moderate Subtask - Perceptual Motor Task



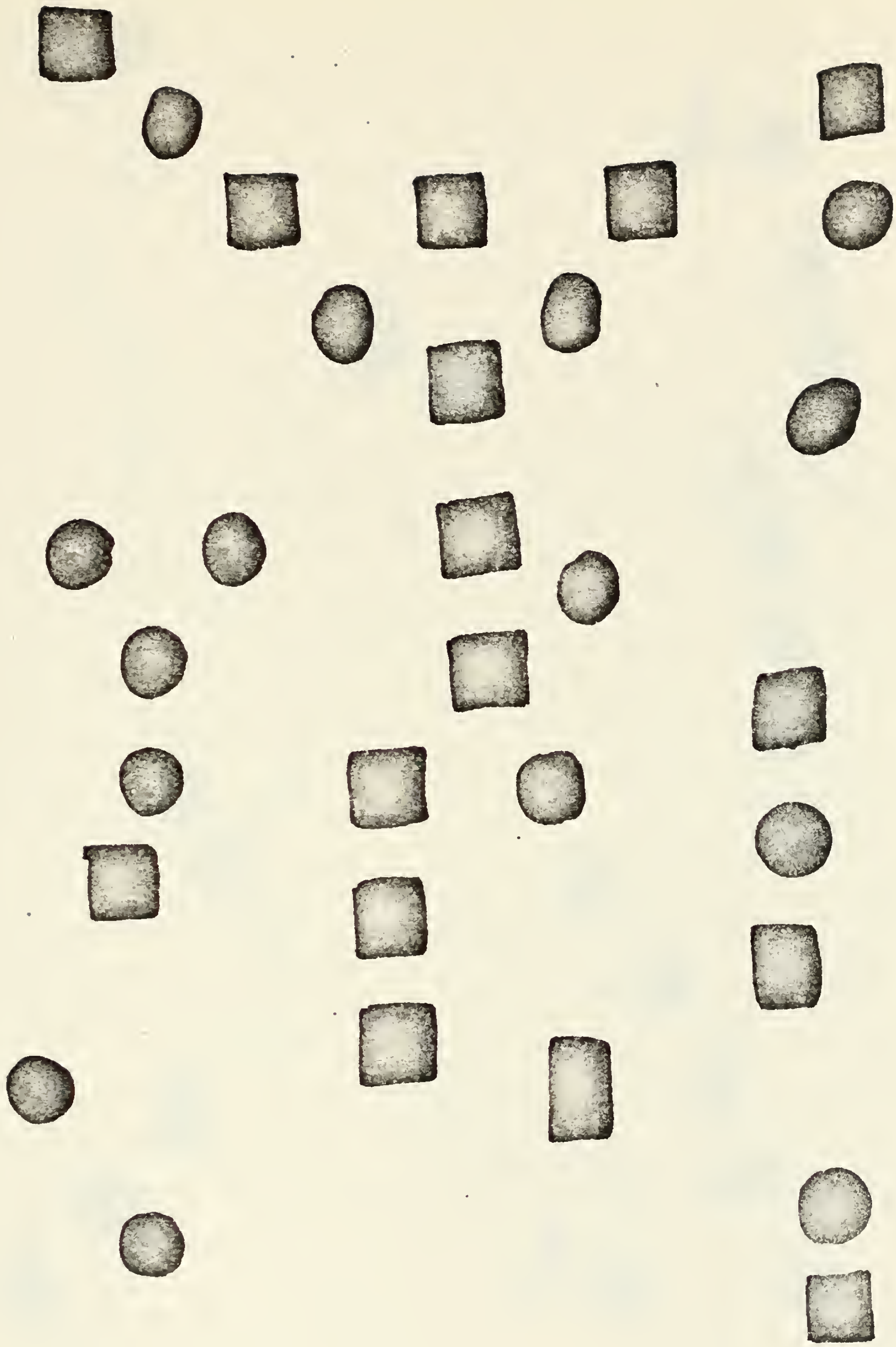
Slide #3 - Moderate Subtask - Perceptual Motor Task



Slide #4 - Moderate Subtask - Perceptual Motor Task

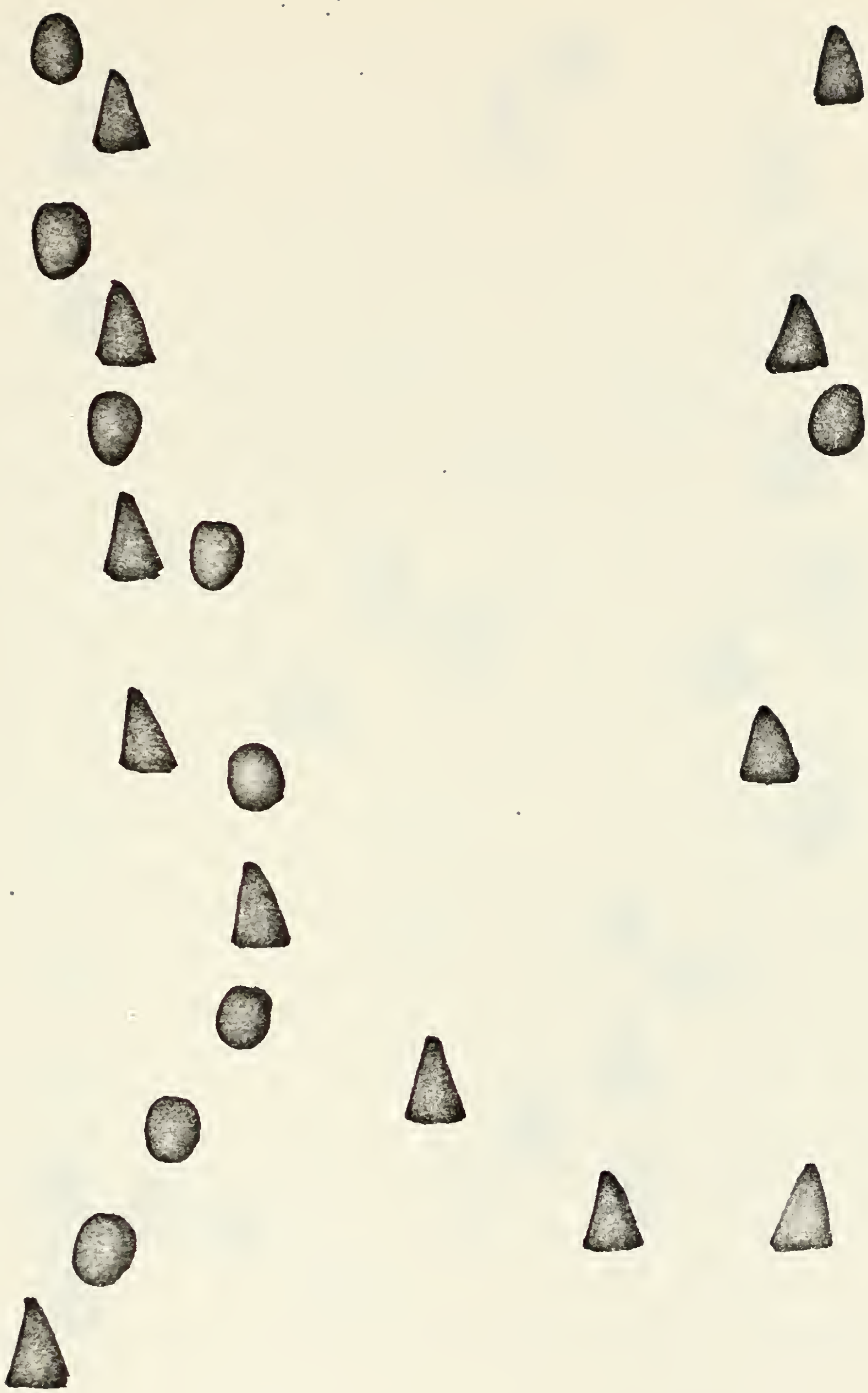


Slide #5 - Moderate Subtask - Perceptual Motor Task

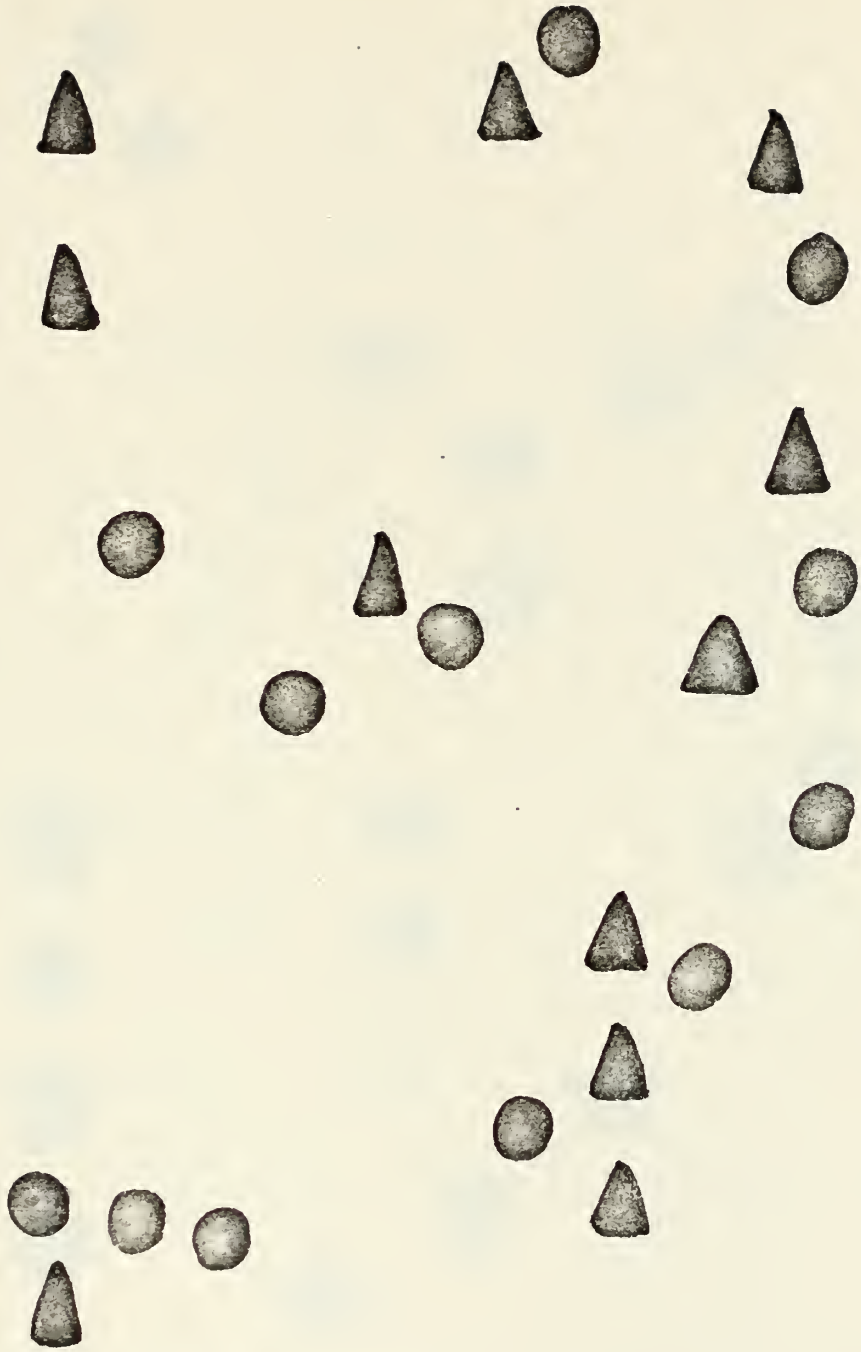


Slide #6 - Moderate Subtask - Perceptual Motor Task

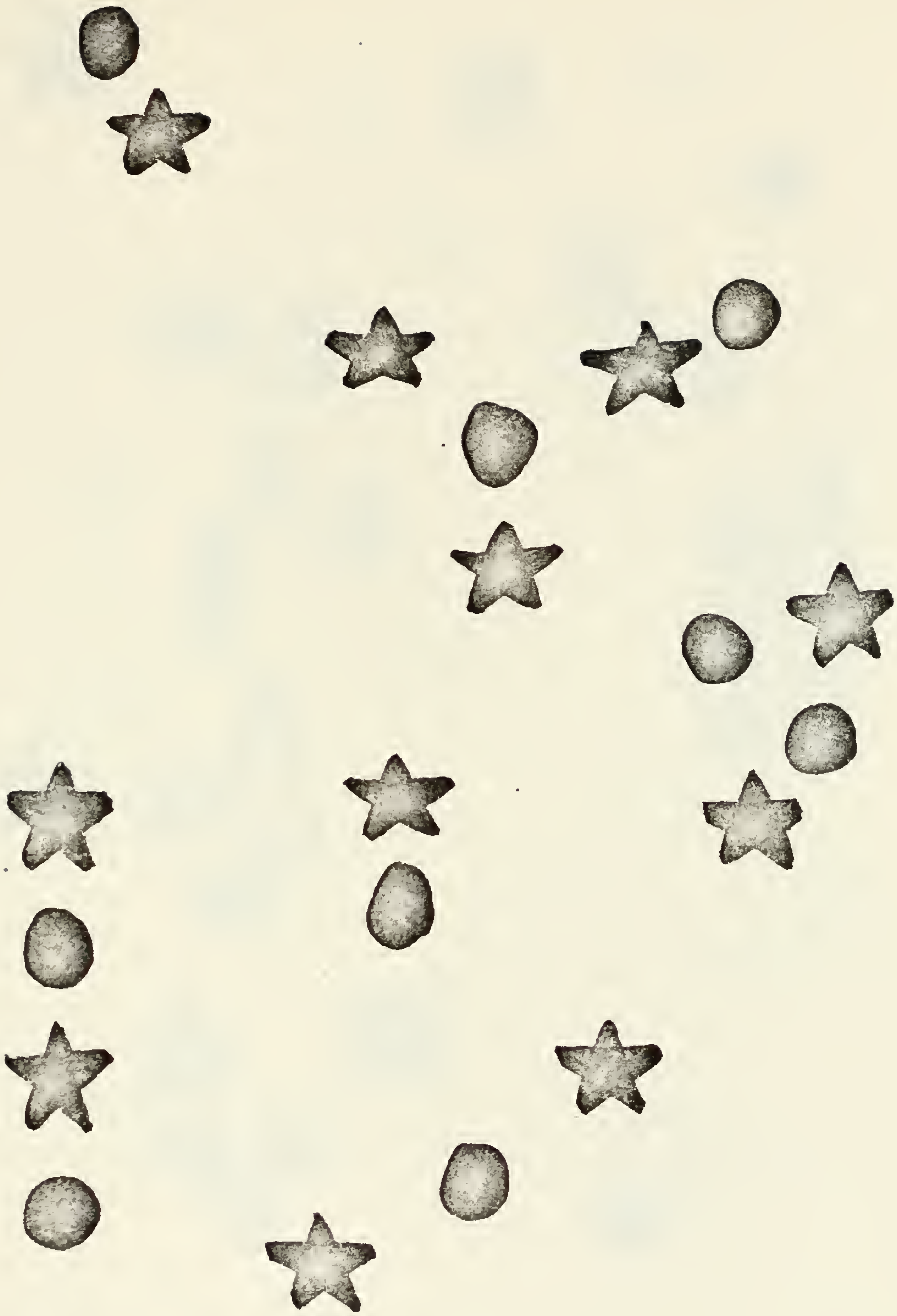
Slide #7 - Moderate Subtask - Perceptual Motor Task



Slide #8 - Moderate Subtask - Perceptual Motor Task

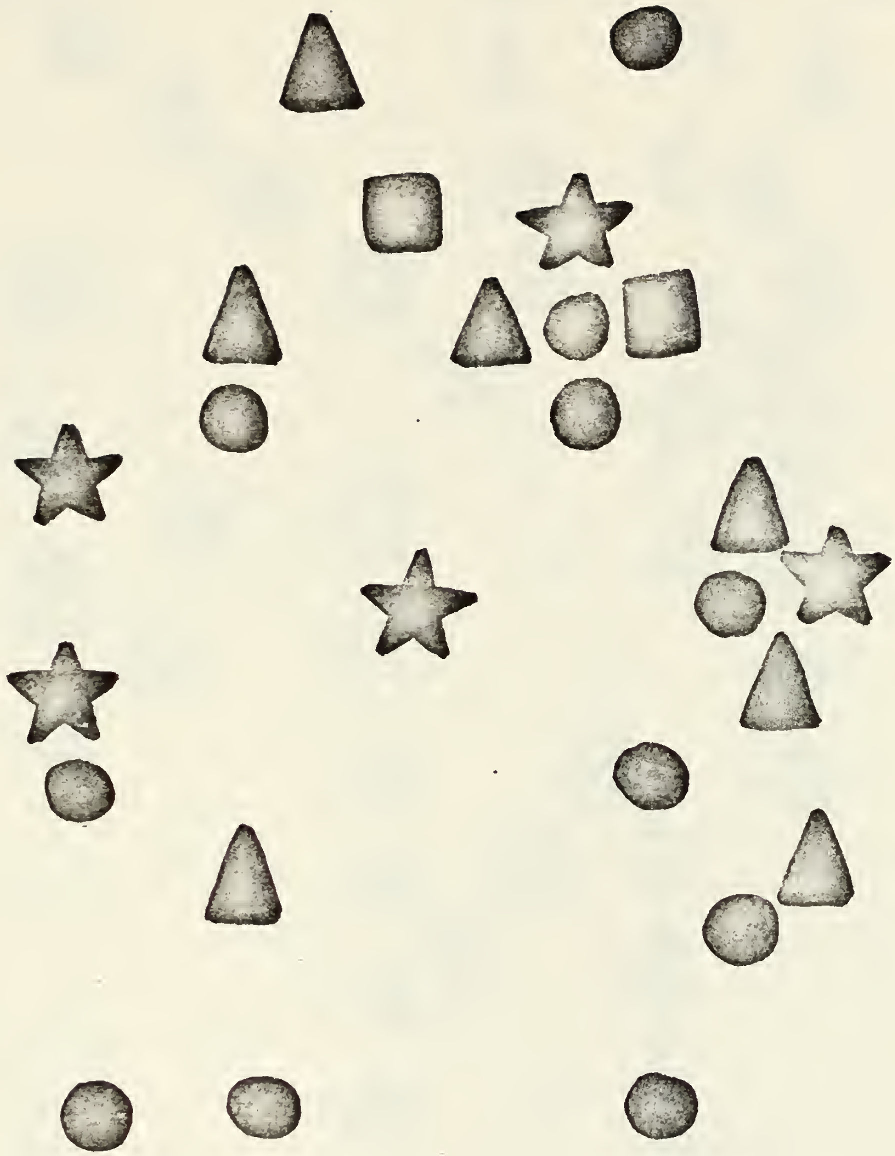


Slide #9 - Moderate Subtask - Perceptual Motor Task

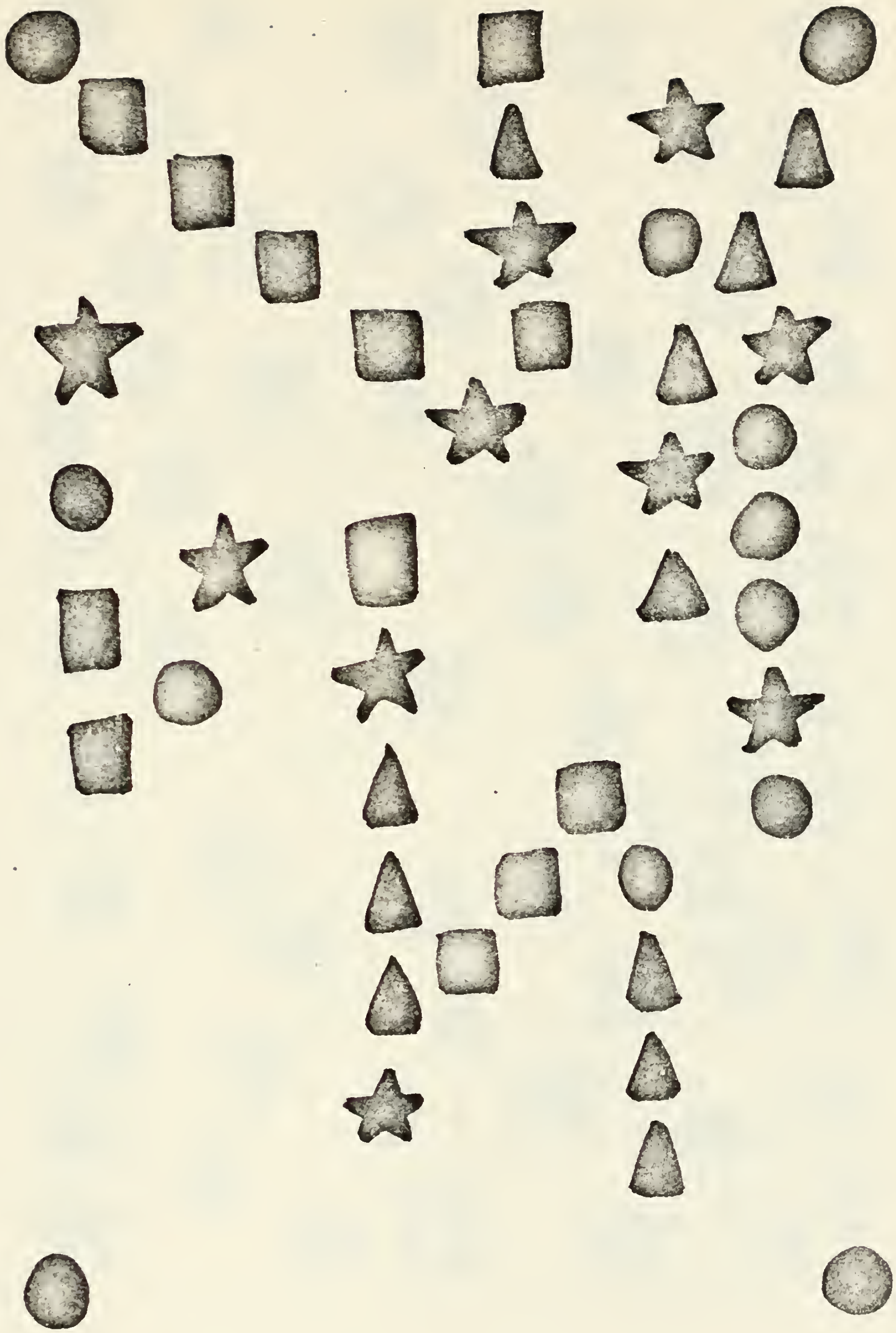


Slide #10 - Moderate Subtask - Perceptual Motor Task

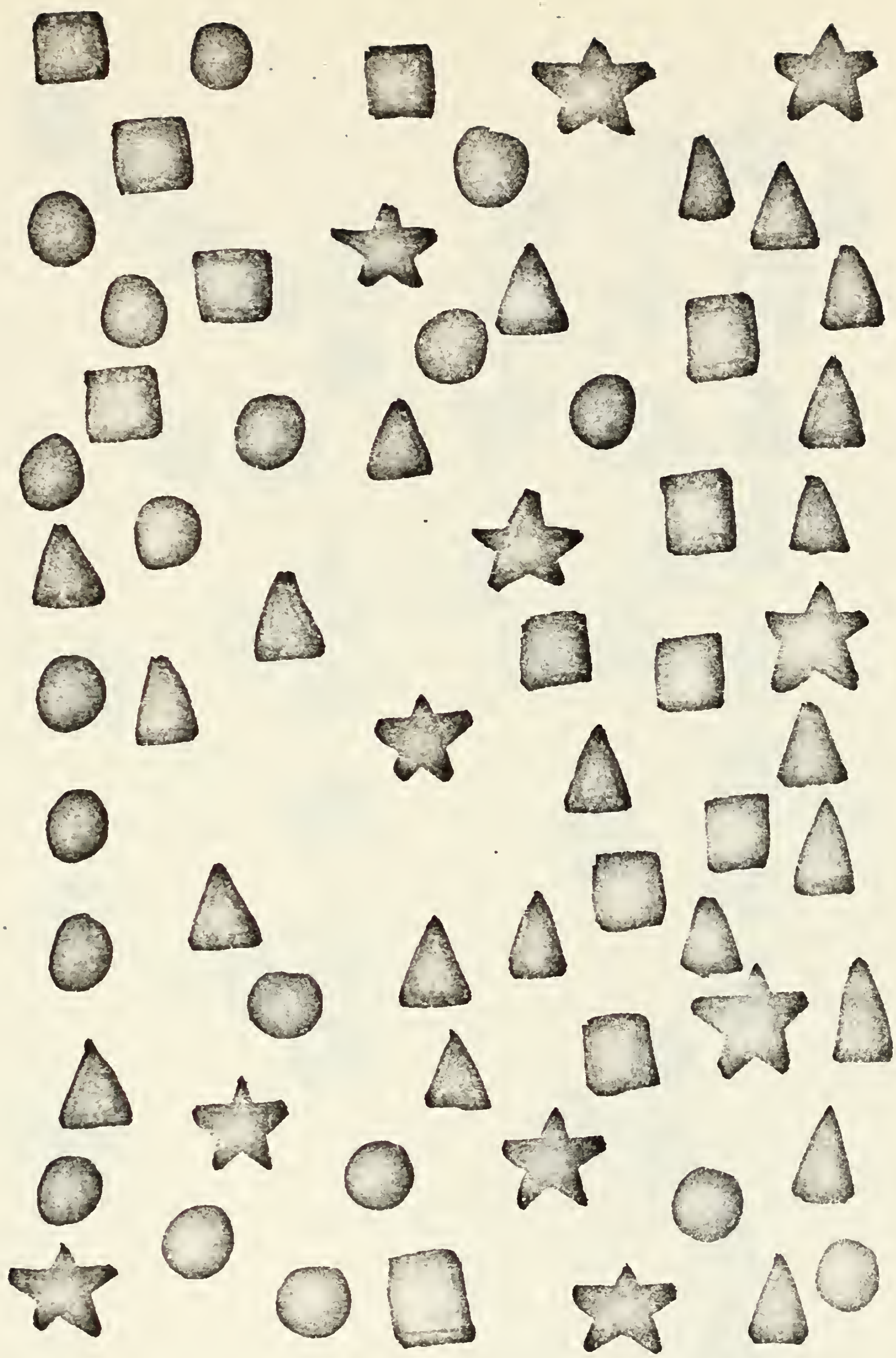
Slide #1 - Difficult Subtask - Perceptual Motor Task



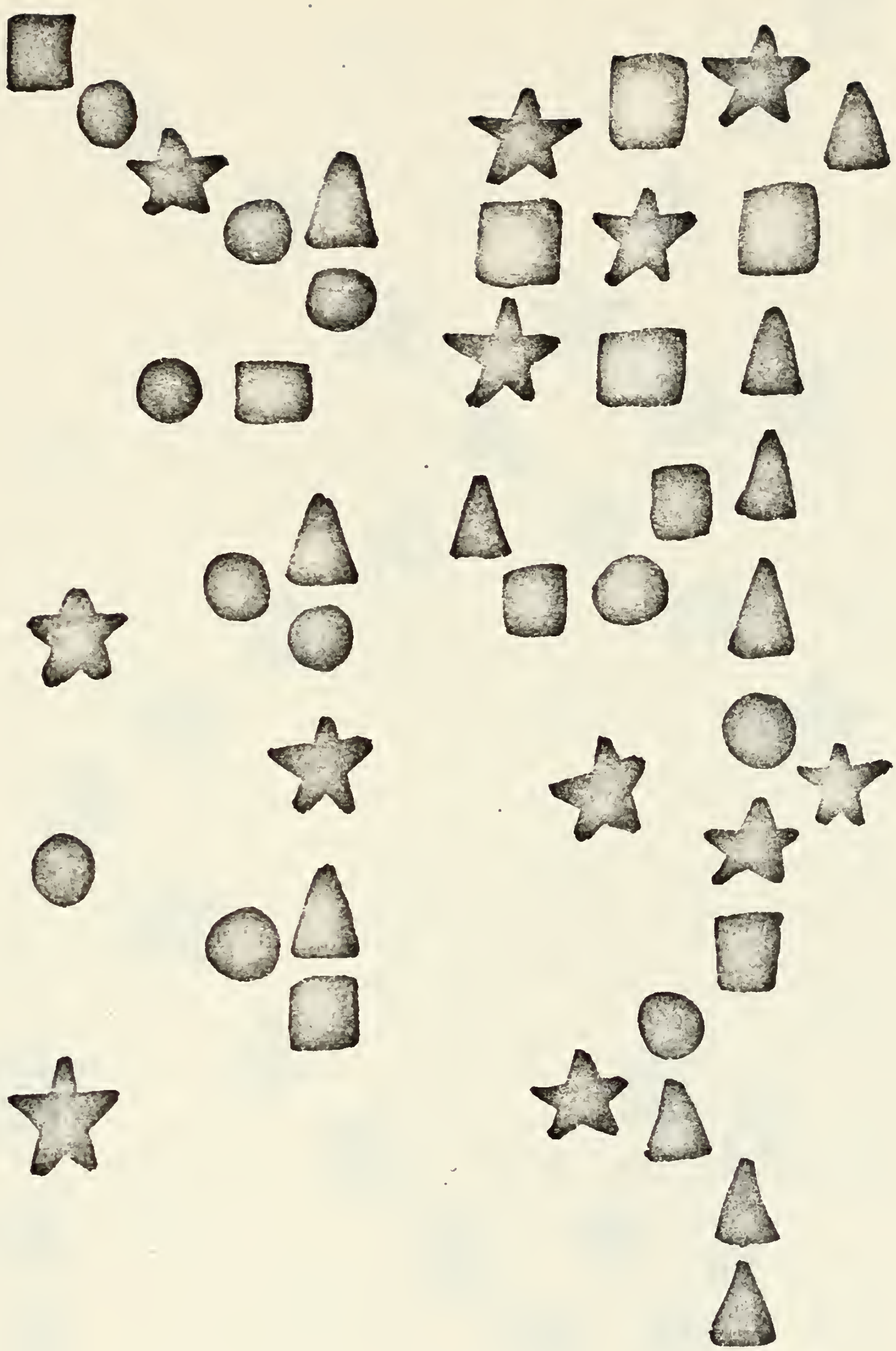
Slide #2 - Difficult Subtask - Perceptual Motor Task



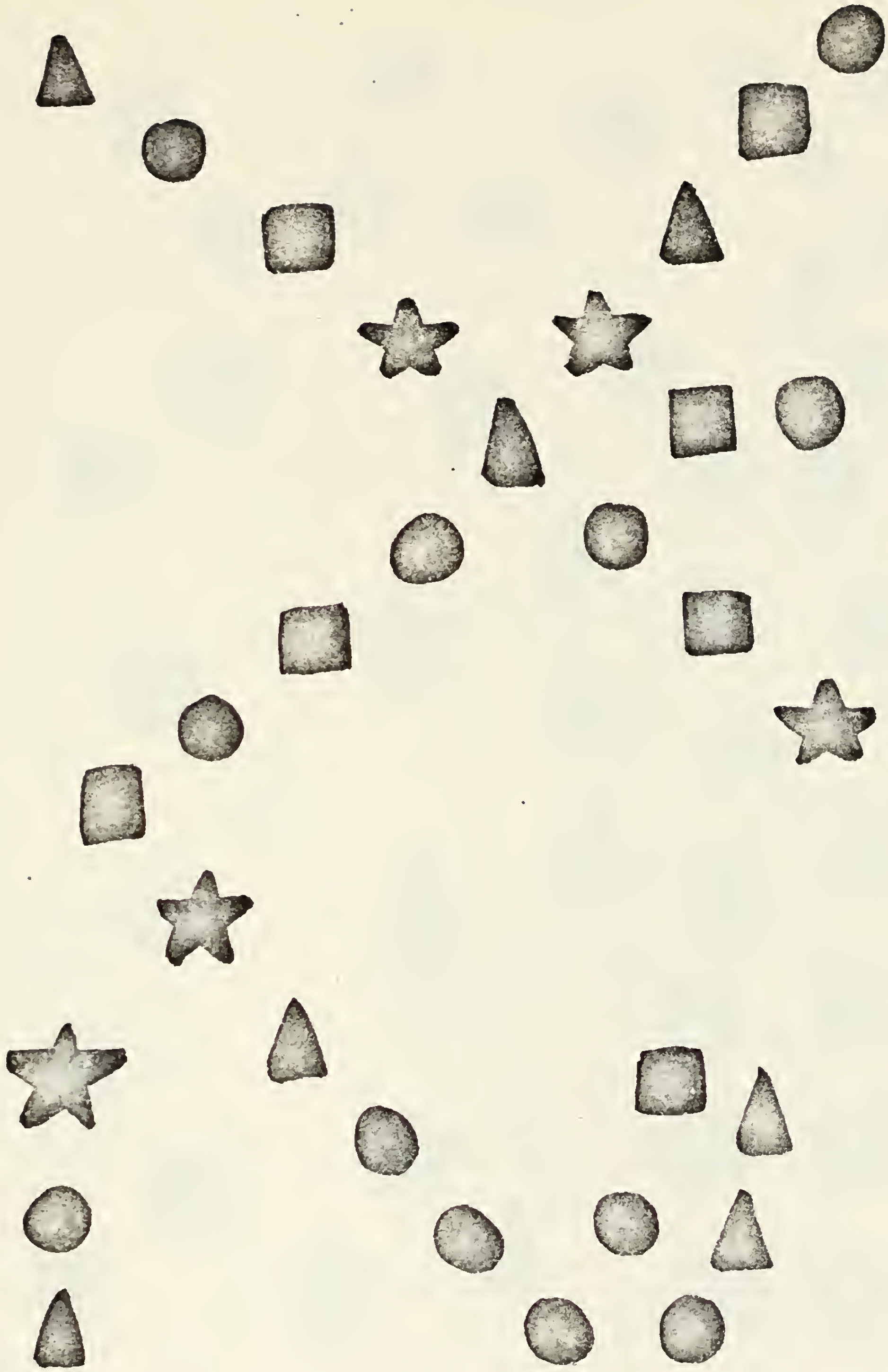
Slide #3 - Difficult Subtask - Perceptual Motor Task



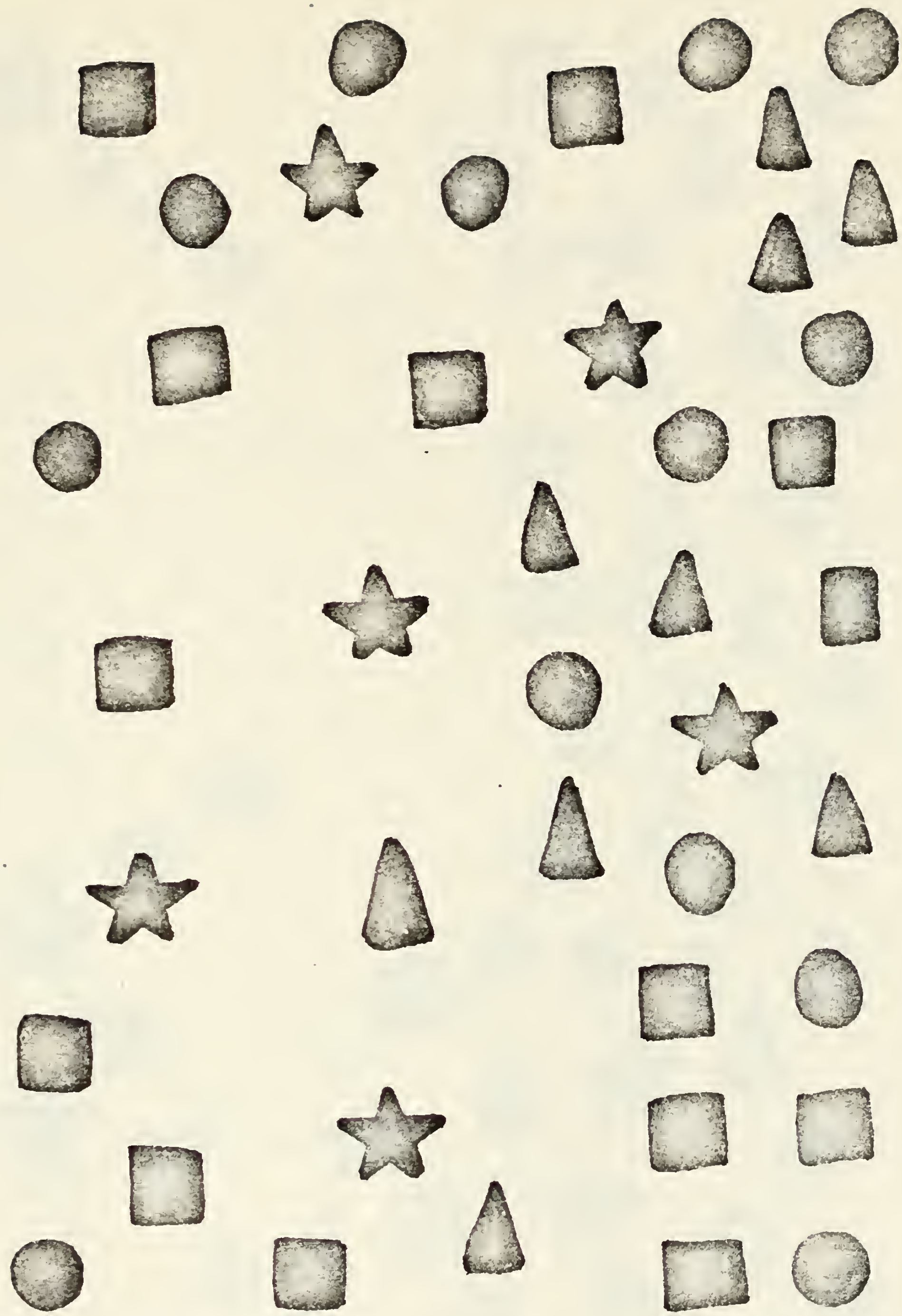
Slide #4 - Difficult Subtask - Perceptual Motor Task



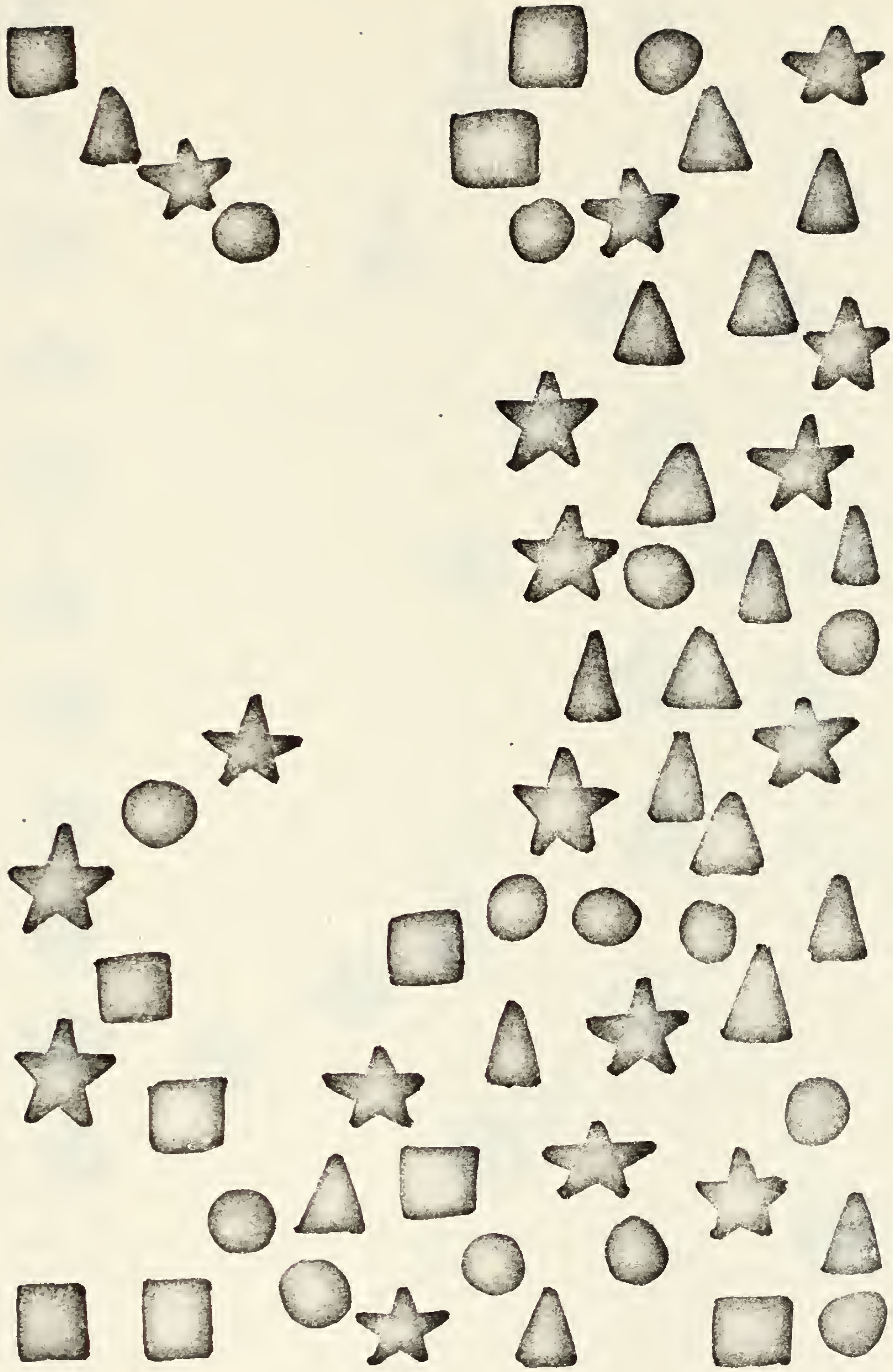
Slide #5 - Difficult Subtask - Perceptual Motor Task



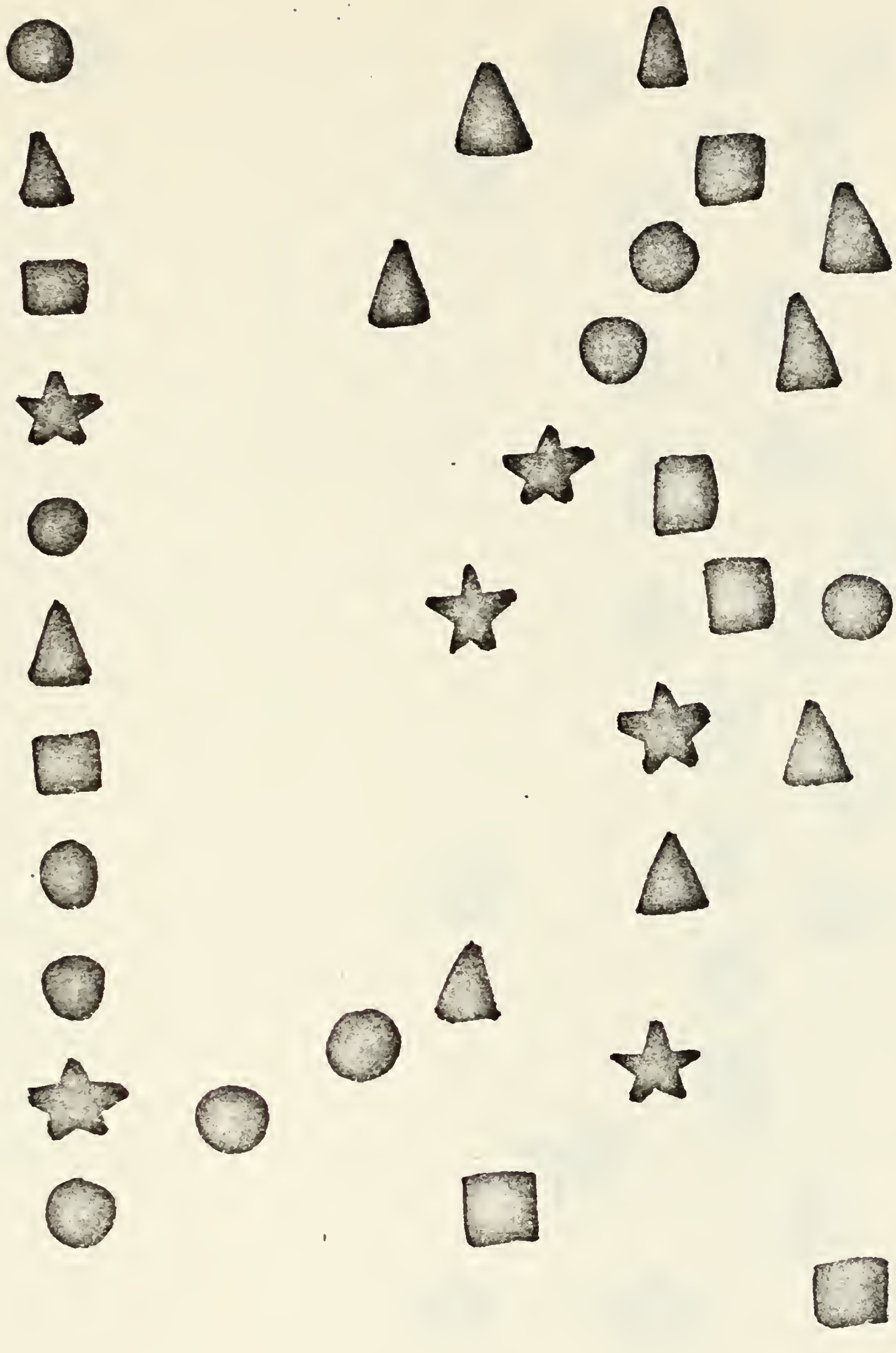
Slide #6 - Difficult Subtask - Perceptual Motor Task



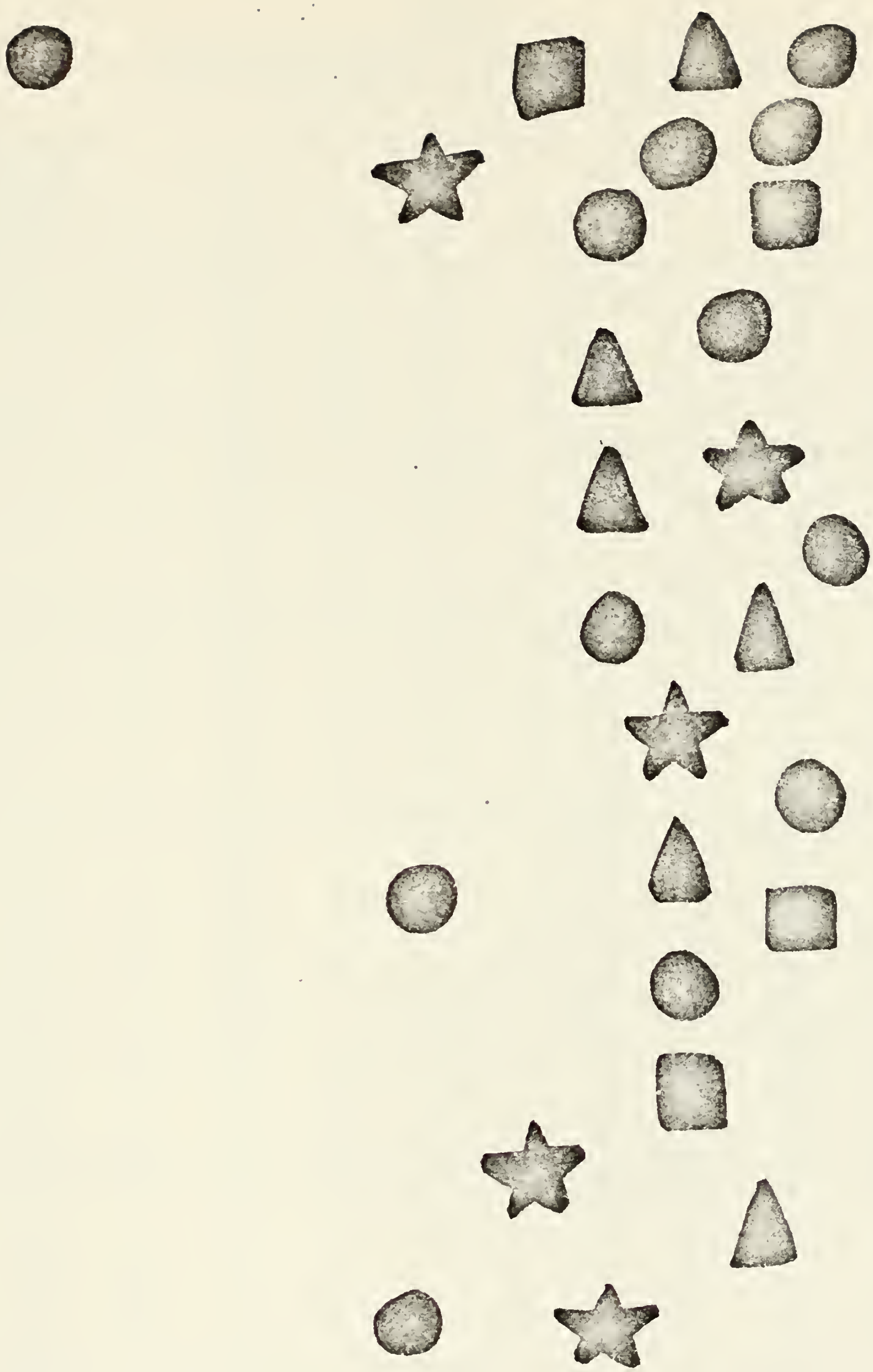
Slide #7 - Difficult Subtask - Perceptual Motor Task



Slide #8 - Difficult Subtask - Perceptual Motor Task



Slide #9 - Difficult Subtask - Perceptual Motor Task



Slide #10 - Difficult Subtask - Perceptual Motor Task

APPENDIX F

DATA

1. Percentage Change of Minimum Pupil Diameters From Mental Mathematics Task

Subject	Trial / Level	1	2	3	4	5
1	E	-16	- 8	- 6	- 4	- 2
	M	- 4	33	29	- 3	5
	D	25	-14	14	18	23
2	E	0	- 7	- 8	10	7
	M	17	12	2	- 7	- 9
	D	5	- 6	-10	-15	-21
3	E	-15	4	- 8	- 4	- 6
	M	- 7	- 9	- 6	- 2	- 7
	D	7	- 9	3	3	- 2
4	E	2	7	7	13	- 4
	M	- 3	3	3	5	5
	D	- 4	6	-11	- 2	- 6
5	E	-14	-10	-16	-14	-16
	M	6	-14	-11	- 3	-14
	D	-23	-18	- 5	-15	-15
6	E	3	- 8	-19	-10	-23
	M	-16	14	10	4	- 6
	D	-16	-18	-10	10	- 2
7	E	-38	- 5	3	3	10
	M	- 4	4	-12	- 4	0
	D	10	10	4	12	6

Subject	Trial / Level	1	2	3	4	5
8	E	11	14	7	14	2
	M	27	16	16	44	57
	D	14	12	16	3	-12
9	E	2	8	0	0	- 8
	M	12	16	19	20	7
	D	- 2	4	22	18	16
10	E	- 8	10	2	0	- 2
	M	5	- 9	0	3	0
	D	26	18	34	44	32
11	E	4	8	20	- 8	- 6
	M	-16	- 3	- 9	- 9	- 3
	D	- 9	-15	-11	22	-15
12	E	17	7	4	2	0
	M	3	2	9	6	15
	D	5	- 5	12	21	21
13	E	23	7	16	25	- 9
	M	- 4	- 3	6	0	-10
	D	2	15	10	14	4
14	E	14	25	14	11	15
	M	6	8	9	13	0
	D	17	7	0	- 3	-16

Subject	Trial / Level	1	2	3	4	5
15	E	-12	-13	- 3	10	8
	M	-21	-18	-12	-14	-10
	D	7	7	10	21	9
16	E	- 6	-26	-15	- 5	-27
	M	0	13	11	16	29
	D	- 5	8	14	29	40
17	E	13	2	7	- 3	-15
	M	-15	5	- 2	8	15
	D	20	34	33	57	59
18	E	-29	-24	-26	-26	0
	M	-26	- 2	- 8	2	- 2
	D	-36	-36	-16	- 2	-18
19	E	- 4	-15	- 5	- 2	-11
	M	-10	18	- 4	17	60
	D	6	-13	- 4	- 4	-16
20	E	16	12	14	5	3
	M	-16	12	12	16	30
	D	28	-14	7	- 4	- 2
21	E	-14	-20	- 6	-13	- 4
	M	-10	-25	-15	-18	- 3
	D	- 6	-22	-10	11	- 3

Subject	Trial / Level	1	2	3	4	5
22	E	0	2	- 4	2	0
	M	0	10	5	10	- 3
	D	10	- 1	5	6	- 3
23	E	- 2	2	- 3	14	12
	M	9	10	7	5	12
	D	9	15	11	17	5
24	E	- 6	4	14	6	4
	M	-10	-25	-29	-10	10
	D	- 2	0	-10	-10	5
25	E	5	20	24	28	35
	M	- 3	2	10	4	3
	D	- 9	- 9	4	0	5

2. Percentage Change of Minimum Pupil Diameters From Arousal Task

Subject	Level \ Trial	1	2	3	4	5
1	E	-19	2	13	6	-33
	M	14	12	- 7	5	23
	D	-10	3	38	30	30
2	E	- 6	4	- 2	4	0
	M	-12	- 6	0	0	- 4
	D	- 3	4	3	33	23
3	E	-18	-18	- 6	-18	-18
	M	-21	- 9	- 7	-12	-17
	D	- 6	- 6	- 8	-11	-13
4	E	0	6	0	- 6	21
	M	-27	-21	-30	-21	-27
	D	- 5	- 4	0	- 9	3
5	E	- 3	15	0	12	7
	M	3	0	0	- 3	3
	D	22	10	3	17	29
6	E	0	10	14	6	10
	M	2	4	9	9	11
	D	- 6	6	2	-16	-20
7	E	- 6	-15	9	9	3
	M	- 4	.2	-10	- 4	4
	D	- 2	4	-10	-20	-22

Subject	Level \ Trial	1	2	3	4	5
8	E	4	20	- 7	4	4
	M	0	17	7	12	10
	D	17	14	13	7	30
9	E	-22	-12	-18	4	0
	M	-25	3	10	3	15
	D	8	13	5	5	28
10	E	9	15	10	- 2	- 5
	M	- 5	- 8	-22	-18	-22
	D	- 6	- 2	- 6	10	15
11	E	13	- 3	-20	-18	-25
	M	5	0	0	-23	- 8
	D	-22	-12	0	0	-17
12	E	0	-10	-12	-13	-12
	M	-19	-16	-16	-13	- 2
	D	3	13	10	3	-14
13	E	-32	-39	-14	- 7	20
	M	-17	- 6	-37	-15	-22
	D	-18	-25	3	8	45
14	E	-11	- 8	-17	- 9	-11
	M	-17	- 5	- 6	-12	-16
	D	2	7	20	- 9	0

Sub-ject	Trial / Level	1	2	3	4	5
15	E	3	7	8	8	10
	M	- 8	5	13	10	13
	D	-10	- 5	- 7	-27	-15
16	E	- 4	7	- 3	6	- 2
	M	-20	- 6	20	6	17
	D	12	14	14	12	17
17	E	10	- 5	-16	-10	-13
	M	-16	- 7	- 4	2	7
	D	-12	- 4	- 4	- 5	- 4
18	E	-20	-40	-20	4	-34
	M	-24	-29	-20	19	15
	D	-17	-14	-17	-31	-20
19	E	-12	- 4	-14	-10	4
	M	-23	-20	- 8	3	13
	D	16	- 7	-14	- 7	14
20	E	8	7	8	12	-17
	M	7	25	20	24	9
	D	-10	4	-17	- 4	-22
21	E	- 8	- 1	-17	-14	-36
	M	- 4	- 1	- 7	5	8
	D	- 4	4	2	9	0

Subject	Trial / Level	1	2	3	4	5
22	E	- 4	- 5	-12	- 4	3
	M	-19	-10	2	- 6	5
	D	-14	14	14	24	34
23	E	-11	13	0	-17	0
	M	0	-11	7	2	9
	D	9	18	2	0	9
24	E	- 3	- 8	- 5	6	- 8
	M	- 4	- 2	-25	-15	- 5
	D	0	- 8	-15	-26	- 5
25	E	-17	-10	0	0	- 2
	M	2	12	13	13	23
	D	2	5	12	10	13

3. Percentage Change of Minimum Pupil Diameters From Perceptual Motor Task

Subject	Trial / Level	1	2	3	4	5
1	E	0	14	12	5	19
	M	-20	12	- 6	- 5	3
	D	- 3	-30	- 8	-11	-11
2	E	-20	-14	-19	-15	5
	M	- 2	19	27	65	32
	D	-10	-19	-10	26	22
3	E	12	7	5	3	- 3
	M	-17	-17	-17	-43	-31
	D	-27	- 4	- 7	30	30
4	E	-20	3	- 5	- 2	-10
	M	- 7	- 4	15	17	10
	D	4	-31	-21	10	20
5	E	-25	-12	-25	-12	0
	M	- 3	- 5	-15	- 7	- 7
	D	-10	-25	-25	-25	-25
6	E	2	24	35	39	35
	M	14	18	32	8	22
	D	-29	- 7	15	4	21
7	E	-13	-15	-50	-12	-40
	M	-44	-30	-44	-33	-36
	D	-20	-20	-33	-30	-33

Subject	Trial / Level	1	2	3	4	5
8	E	21	18	21	43	10
	M	3	12	17	12	4
	D	8	6	- 4	- 6	- 2
9	E	-38	-18	-24	27	-18
	M	-14	-18	-19	-16	-14
	D	-14	-12	-19	10	-17
10	E	-24	-34	-26	-19	-17
	M	-10	-17	-15	-19	-12
	D	- 5	-12	-14	-12	-10
11	E	-33	-33	-38	-30	-46
	M	- 8	-23	-17	-18	-18
	D	-23	-25	-48	-30	-25
12	E	2	- 2	2	- 2	0
	M	-17	4	-15	- 2	-27
	D	- 4	-10	-15	- 7	- 4
13	E	-20	-33	- 9	3	-14
	M	39	-35	-18	-41	-24
	D	13	-11	-28	-35	-41
14	E	8	11	26	28	26
	M	23	.47	50	50	39
	D	21	21	45	46	33

Subject	Trial / Level	1	2	3	4	5
15	E	-15	3	18	27	25
	M	0	2	6	6	2
	D	15	17	17	22	22
16	E	- 3	- 2	1	11	16
	M	- 3	12	10	4	8
	D	- 6	-10	- 8	- 6	- 8
17	E	-20	-23	-15	-15	- 6
	M	6	2	- 2	- 4	- 6
	D	-15	- 4	-19	-26	-25
18	E	3	7	3	- 3	-13
	M	2	4	19	27	38
	D	-12	-14	-14	-12	- 6
19	E	- 9	- 7	0	9	7
	M	12	25	22	3	25
	D	21	23	32	16	21
20	E	- 5	5	-10	12	3
	M	- 8	- 6	2	10	-20
	D	-24	0	-10	0	0
21	E	- 8	- 8	- 2	-12	3
	M	- 5	6	-15	- 7	-11
	D	- 8	0	-10	-20	-17

Subject	Trial / Level	1	2	3	4	5
22	E	-26	-18	0	- 2	- 3
	M	-19	1	3	3	- 2
	D	- 4	- 3	- 2	- 7	- 4
23	E	-13	15	5	4	-11
	M	2	2	7	- 5	- 7
	D	- 6	-14	-29	-24	-33
24	E	-28	- 4	-13	- 8	-14
	M	5	0	5	- 5	-21
	D	-12	-12	0	- 5	- 7
25	E	- 3	6	-12	-15	- 3
	M	2	- 5	- 4	- 2	8
	D	- 8	- 4	-22	-23	-37

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Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Cognitive Load and Pupillary Response

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis; June 1972

5. AUTHOR(S) (First name, middle initial, last name)

Robert E. Scheidig

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1972		54

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

25 Naval Postgraduate students were used to test the hypothesis that long-term cognitive loading (information overloading) would result in pupillary constriction. Continuous mental mathematics was used as the cognitive loading task, with control tasks for arousal (looking at photos of nude women) and perceptual motor effort (counting dots with a button-press). Each task had 3 levels of difficulty. Analysis of the percentage change in minimum pupil diameter over 10 continuous trials showed significant effects for tasks and levels of difficulty and a complex pattern of pupillary dilations and constrictions over the last four trials that tended to support the hypothesis. Trends for maximum and minimum pupil diameters, percent change and latency of peak pupil diameters, and blink rates are shown.

DD FORM 1473 1 NOV 65 (PAGE 1)

S/N 0101-807-6811

Security Classification

A-31408

Unclassified

Security Classification

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Cognitive Load						
Pupillary Response						
Percentage Change in Peak Pupil Diameter						
Percentage Change in Minimum Pupil Diameter						
Latency Time to Peak Pupil Diameter						
Blink Rate						
Information Overloading						

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